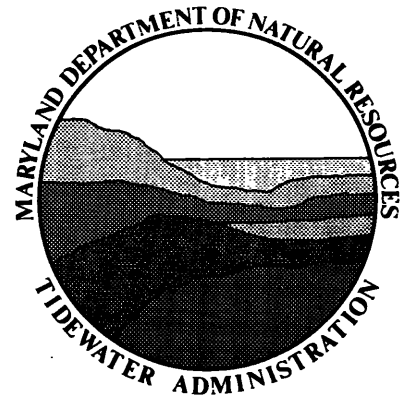
PPRP-R-23

PPRP

DOCUMENTATION OF THE PPRP GAMMA SPECTROMETRY METHODS: A GUIDE TO DATA ACQUISITION AND SPECTRAL PROCESSING

December 1996

MARYLAND POWER PLANT
RESEARCH PROGRAM



The Maryland Department of Natural Resources (DNR) seeks to preserve, protect and enhance the living resources of the State. Working in partnership with the citizens of Maryland, this worthwhile goal will become a reality. This publication provides information that will increase your understanding of how DNR strives to reach that goal through its many diverse programs.

John R. Griffin
Secretary
Maryland Department of Natural Resources

PPRP-R-23

DOCUMENTATION OF THE PPRP GAMMA SPECTROMETRY METHODS: A GUIDE TO DATA ACQUISITION AND SPECTRAL PROCESSING

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December 10, 1996

FOREWORD

This report contains a detailed description of the methods used to set-up, operate, and maintain the gamma-ray spectrometry equipment in the radioecology laboratory of the Maryland Department of Natural Resources, Power Plant Research Program. The primary purpose of these methods is to determine the concentration of radionuclides in environmental samples. Described in this report are the components and operation of the gamma-ray spectrometry equipment and software used to complete these measurements. This report was produced under Contract Number PR96-055-001 to Versar, Inc., from the Maryland Department of Natural Resources under the direction of Richard I. McLean.

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ABSTRACT

The Maryland Department of Natural Resources, Power Plant Research Program (PPRP), conducts monitoring to determine the concentration of radionuclides in environmental samples. Radionuclide concentrations are measured using high-resolution gamma spectrometry. In 1995, a PC-based data acquisition system was purchased and installed to improve the efficiency of laboratory operations, reduce annual equipment maintenance costs, and improve data management. The new system replaced a ten year old VAX-based system. Described in this report are the components and operation of the new gamma-ray spectrometry equipment and the application of the new spectrum acquisition and processing software. Instructions concerning the setup of hardware and software used within the new gamma spectrometry system, analysis of environmental samples, and data management are provided in a detailed, step-wise format. This document represents a training manual for new staff that may participate in PPRP radioecology monitoring efforts.

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1.0 INTRODUCTION

The Power Plant Research Program (PPRP) of Maryland sponsors research and conducts environmental monitoring to assess the environmental and health related impacts of nuclear power plants in and around Maryland. One component of PPRP's activities is the monitoring of radionuclide concentrations in environmental samples collected in the vicinity of power plants that introduce or potentially introduce, radionuclides into the environment. Principal PPRP monitoring efforts include monitoring at Calvert Cliffs Nuclear Power Plant (CCNPP) in Calvert County, MD since 1975 and monitoring at Peach Bottom Atomic Power Station (PBAPS) in York County, PA since 1978. Both nuclear power plants release measurable quantities of radioactive material to the environment as permitted under their operating licenses from the U.S. Nuclear Regulatory Commission (USNRC). The objectives of the monitoring are to:

- Define the relative contribution of natural, weapons, and power plant produced radionuclides;
- Determine the fate of power plant released radionuclides; and,
- Estimate radiation dose to human populations resulting from the operation of nuclear power plants.

In addition to conducting studies to address the objectives stated above, the PPRP radioecology program provides laboratory support in the event of a radiological emergency involving either CCNPP or PBAPS.

Documentation of the PPRP radioecology procedures is important to ensure that all environmental monitoring objectives are implemented efficiently and consistently over time. Four manuals were developed to document standard operating procedures. These reports include information regarding the collection and preparation of environmental samples (Maranto 1991a), the structure and format of the radioecology data base (Frithsen et al. 1996), and emergency response procedures (Maranto 1991b). This report contains a description of the equipment and procedures used to measure the concentrations of radionuclides in environmental samples. The general content of and relationships between the four reports are shown in Figure 1-1.

Measurement of radionuclide concentrations in environmental samples are completed using gamma-ray spectrometry. The components of the gamma-ray spectrometer consist of high-purity germanium detectors, multichannel analyzer, and a computer with data acquisition and spectral processing software. Germanium detectors are commonly used for low-level gamma-ray counting because of their high efficiency (typically 25 %) and good resolution, typically 1.8 keV (FWHM) at 1.33 MeV and 0.9 keV (FWHM) at 122 keV. FWHM is the width of the peak at half height after the subtraction of the continuum under the peak. Multichannel analyzers are required to categorize, accumulate, and store information about gamma-ray photons sensed by the germanium detector. The computer facilitates spectral data display, storage, and processing to produce final results.

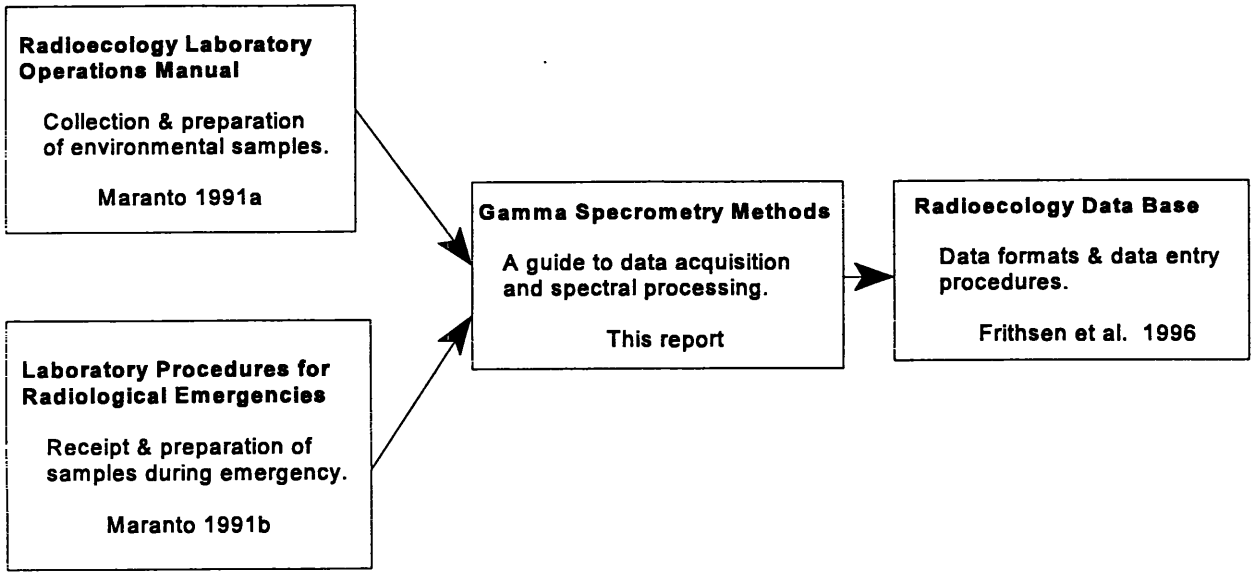


Figure 1-1. Correlation and general contents of the four procedure manuals for the PPRP radioecology laboratory.

During the period 1986 to 1995, the data acquisition system used by the PPRP radioecology laboratory was comprised of a DEC MicroVax II Nuclear Data, Inc. ND9900. A new data acquisition system was purchased and installed in 1995 to improve the efficiency of laboratory operations and lower annual equipment maintenance costs. This new data acquisition system consisted of Genie-PC software produced by Canberra running on an IBM personal computer using the OS/2 operating system.

This report is organized into three sections. This introduction is followed by Section 2 containing a discussion of the background and basic theory of gamma-ray spectrometry. Section 3 presents the procedures for operating the new Genie-PC data acquisition and spectral processing software.

2.0 BACKGROUND AND THEORY

2.1 GAMMA-RAY SPECTROMETER

The concentration of gamma-emitting radionuclides in environmental samples is determined using a gamma-ray spectrometer that consists of a high-purity germanium detector and shield, a multichannel analyzer (MCA), and a personal computer (Figure 2-1). Gamma-ray photons entering the detector interact with the semiconductor diode in an area which is sensitive to ionizing radiation. As the gamma photons strike this region, the detector generates pulses of electrons that are transmitted to a multichannel analyzer through a preamplifier and other hardware. The strength of the electric pulse is proportional to the energy deposited by the gamma photons striking the detector and the number of pulses is proportional to the number of photons impacting the crystal. Each pulse is converted to a digital signal that is accumulated in one of 4096 channels representing 0.5 keV gamma-ray photon energy levels ranging from 1 to 2048 keV. The acquisition interface module (AIM) picks up the digital signals from the analog to digital converter (ADC) and transmits them through the network to the PC. In case of computer failure, the AIM stores all raw spectral data in memory.

The current gamma-ray spectrometer in the PPRP radioecology laboratory consists of two detectors. A short description of the spectrometry equipment components is provided in Table 2-1. Spectrum processing software uses the raw spectral data to identify and quantify radionuclides in environmental samples.

2.2 SPECTRUM PROCESSING SOFTWARE

The basic processing steps to generate a radioecology data base from raw sample spectra, and the software applications needed to perform these procedures are shown in Figure 2-3.

Tasks completed using the spectrum processing software include: integration of peak heights, subtraction of background radiation counts, normalization for counting or spectrum acquisition time, matching specific energy peaks to known radionuclides, and converting counts per unit time to activity (disintegrations per unit time) based upon detector efficiency and the branching ratios for gamma-ray photons from specific radionuclides.

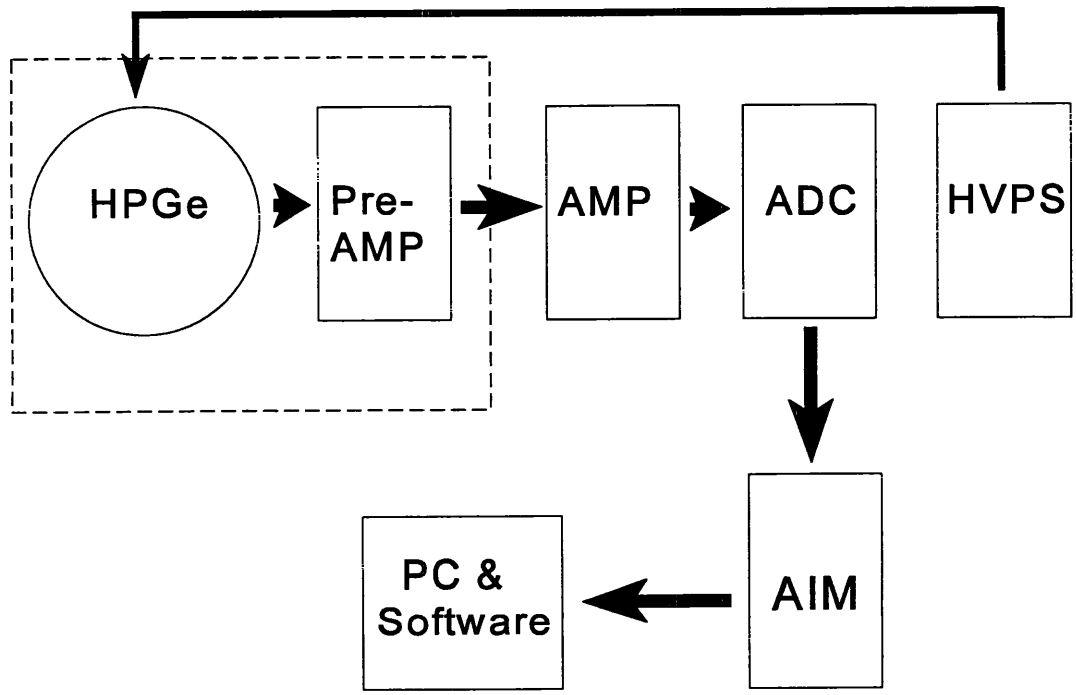


Figure 2-1. Schematic diagram of a gamma-ray spectrometer system showing the high-purity Germanium detector (HPGe), pre-amplifier (Pre-AMP), amplifier (AMP), analog to digital converter (ADC), high-voltage power supply (HVPS), acquisition interface module (AIM), and personal computer (PC).

Table 2-1. Components of the gamma-ray spectrometer system (CANB1-25 and ORTC1-25) currently used in the PPRP radioecology laboratory

Hardware	Manufacturer	Model	Year
HPGe[a]	Canberra	GC2518	1993
AMP[a]	Canberra	2025	1993
ADC[a]	Canberra	8701	1993
HVPS[a]	Canberra	3106D	1993
HPGe[b]	Ortec	GEM 25185	1983
AMP[b]	Ortec	572	1987
ADC[b]	Canberra	8701	1995
HVPS[b]	Ortec	459	1987
AIM[c]	Canberra	556	1995
PC[c]	IBM	6885-4U0	1995

[a] Component of the gamma-ray spectrometer called CANB1-25.
[b] Component of the gamma-ray spectrometer called ORTC1-25.
[c] Component utilized by both gamma-ray spectrometers, CANB1-25 and ORTC1-25.

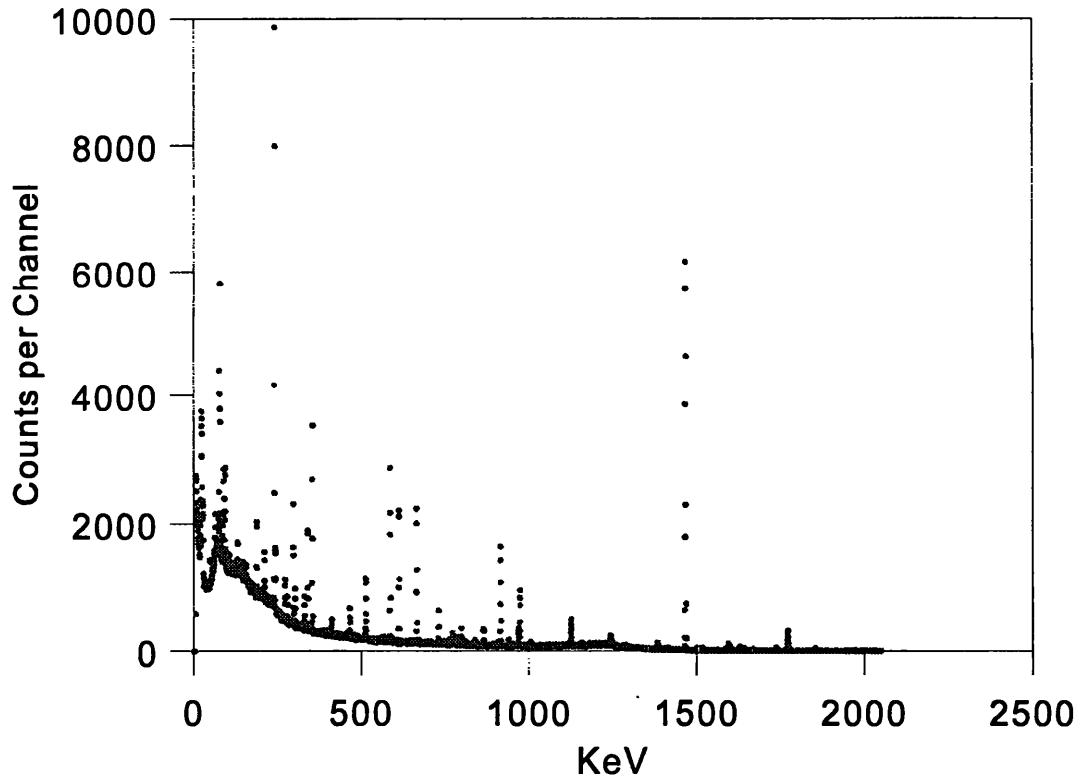


Figure 2-2. Sample spectrum captured from the Canberra Genie-PC software. Spectrum corresponds to a sediment sample collected in the vicinity of Calvert Cliffs.

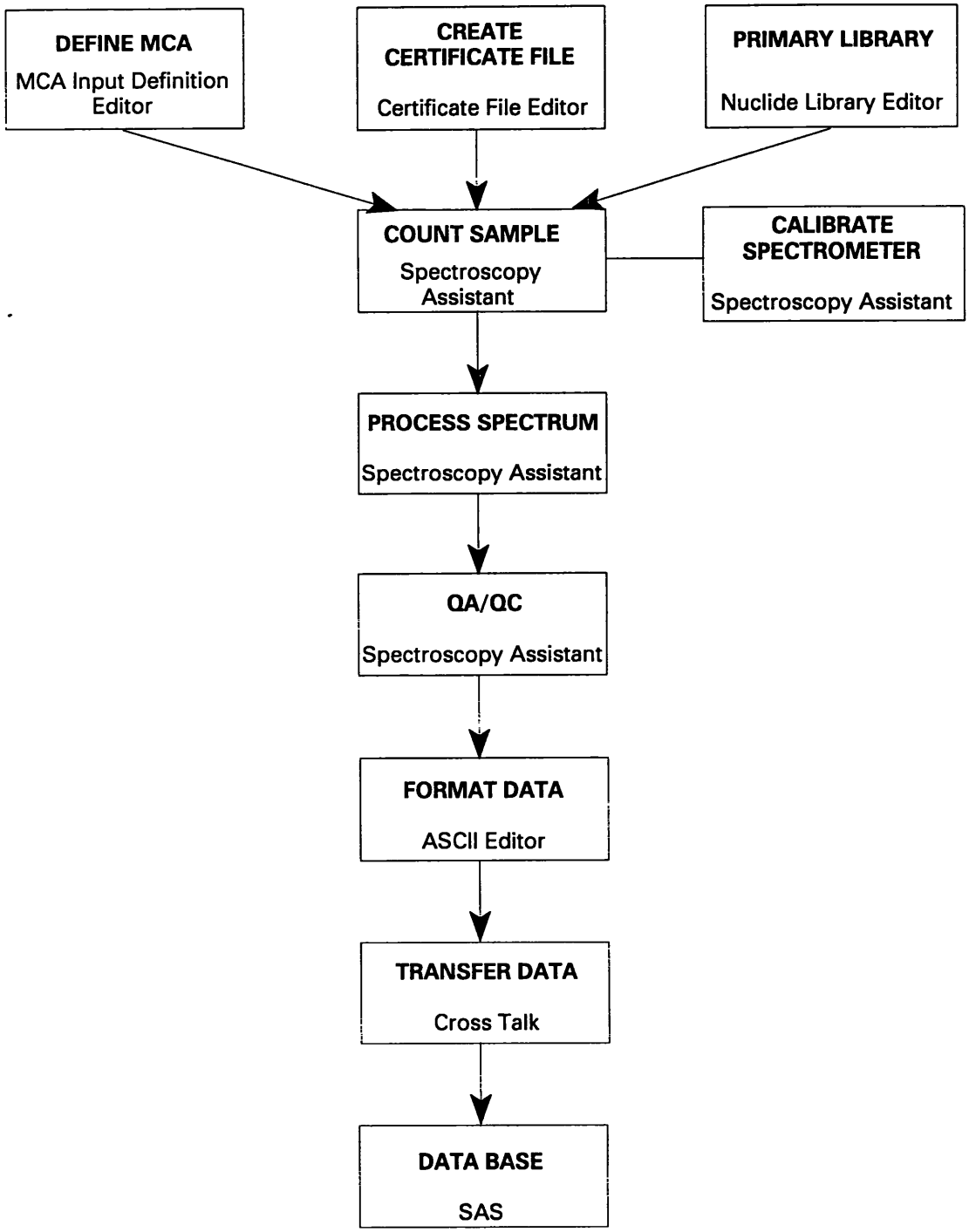


Figure 2-3. Schematic diagram showing the steps to convert raw spectral counts to activity, using Canberra Genie-PC software applications, and the subsequent steps to merge the data with the radioecology data base.

2.3 DATA ANALYSIS

This section contains descriptions of the algorithms used by Genie-PC spectral processing software to estimate the activity, uncertainty, and minimum detectable concentrations of radionuclides in environmental samples. The environmental samples processed as part of PPRP radioecology monitoring efforts typically contain only picocurie quantities of radionuclides. A radionuclide is detected when the count rate for its constituent photopeaks are higher than the background continuum count rate. The total abundance of the constituent peaks detected must also pass certain criteria. If a nuclide of interest is not found in the sample, a minimum detectable activity is calculated by the Genie-PC software.

2.3.1 Sample Activity

The activity of a sample is a measure of the amount of a radionuclide that is present expressed in terms of the number of disintegrations per second. The SI unit of activity is the curie. One curie (Ci) of any radionuclide is the quantity of the radionuclide decaying at the rate of 3.7 x 10^{10} (37 billion) disintegrations per second. Because the concentrations of radionuclides in an environmental sample are small, activity is commonly reported in units of picocurie (10^{-12} curies). Table 2-2 shows the standard equation used to calculate the concentration of each radionuclide decay corrected to the date of collection.

2.3.2 Error Estimation

Uncertainties in the activity of each radionuclide are reported at the 95% (2-sigma) confidence level. The two-sigma counting error associated with the activity of each radionuclide in a sample is defined by the equation given in Table 2-3.

2.3.3 Minimum Detectable Activity

In gamma-ray spectrometry, the term used to describe the detection limit in units of activity is commonly called the minimum detectable activity (MDA). The Genie-PC spectrum processing software calculates MDAs for all gamma-ray emitting radionuclides. The MDA is defined by the equation given in Table 2-4.

Table 2-2. Calculation of activity for each energy line in the sample spectrum. Source: Canberra 1995.

The activity (A) of a nuclide of interest per unit volume or mass of sample is given by:

$$A=\frac{S}{VEBCTK_w}$$

where

S = The net peak area (counts)
V = The mass or volume of sample
E = Counting efficiency for the peak of interest
B = The branching ratio of the gamma-ray peak
C = The conversion factor for reporting activity (i.e., 1 pCi = .037 dps)
T = The sample counting time (live) in seconds
K_W = The decay correction factor

$$K_W=e^{-\frac{\ln(2)t_w}{T_{1/2}}}$$

$T_{1/2}$ = The half life of the nuclide
t_w = The elapsed clock time from the time the sample was taken to the beginning of the measurement

Table 2-3. Determination of the two-sigma counting error. Source: Canberra 1995.

The uncertainty (σ_A) of the activity of nuclide A is given by:

$$\sigma_A=A\sqrt{\left(\frac{\sigma_R}{100}\right)^2+\left(\frac{\sigma_S}{S}\right)^2+\left(\frac{\sigma_\varepsilon}{\varepsilon}\right)^2+\left(\frac{\sigma_y}{y}\right)^2}$$

where

A = The activity per unit volume of the sample
σ_R = The user defined random (counting) error (%)
σ_S = The uncertainty of the net peak area S
σ_ε = The uncertainty of the effective efficiency ε
σ_y = The uncertainty of the branching ratio y

Table 2-4. Calculation of the minimum detectable activity. See Table 2-2 for definitions. Source: Canberra 1995.

Minimum detectable activity is given by:

$$MDA = \frac{L_D}{VEBTK_w}$$

where

$$L_D = K^2 + 2L_C$$

K = The abscissas of the normal (Gaussian) distribution corresponding to confidence levels

Confidence levels and K values.	
CL	K
90%	1.282
95%	1.645
99%	2.326

$$L_C = K\sigma_0 = K\sqrt{\mu_F + \mu_I + \sigma_F^2 + \sigma_I^2}$$

μ_F = The "true" calculated continuum under the peak
μ_I = The "true" measured background interference — net peak area
σ_F = The variance of B (calculated continuum under the peak due to Compton scattering)
σ_I = The variance of I (measured background interference—net peak area)

3.0 PROCEDURES

In this section are step by step procedures for the set-up, calibration, operation, and maintenance of gamma-ray spectrometry hardware and Genie-PC acquisition and spectral analysis software. The procedure for radionuclide data validation, management, and transmittal are also included.

Prior to using the Genie-PC software the user should be familiar with the following terminology:

- **Select** Point to an item and click mouse button 1
- **Open** Point to an item and double-click mouse button 1

3.1 SET-UP OF GAMMA-RAY SPECTROMETER HARDWARE

This section describes how to connect the components of the gamma-ray spectrometer. At the core of the gamma-ray counting system are two HPGe detectors coupled to nuclear instrumentation modules (NIMs), an acquisition interface module (AIM), and a personal computer running Genie-PC software. The various components are linked together by a series of cables. Data can be acquired simultaneously from two analog to digital converters (ADCs) routed through an acquisition interface module (AIM) which is connected to the ethercard on the back of the PC via coaxial communications cable. To install the instruments follow these steps:

1. High-purity germanium (HPGe) detectors are encased in an aluminum cylinder and are mounted on a 30-Liter dewar which contains the liquid nitrogen reservoir. For the Applied Physical Technology (APT) shield, raise the detector/dewar assembly using an adjustable jack until at least 3 inches of the detector casing is extending into the shield. For the Gamma Products shield, the detector must be detached from the dewar and lowered through the opening in the floor of the detector, then reattached to the dewar.
2. If the cryostat in the HPGe detector has not been chilled, fill the detector with liquid nitrogen (refer to Section 3.2).
3. If the power to the nuclear instrumentation module (NIM) bin is on, turn it off.
4. Insert the HVPS, AMP, ADC, and AIM into slots in the NIM bin.
5. Connect the large coaxial cable from the HVPS output to the detector.
6. Connect the detector output 1 (small coaxial cable) to the amplifier input and AMP output (short coaxial cable — 3 in.) to the input of the ADC.
7. Connect the gray cable from the detector PRE-AMP to the pre-amp output of the AMP.

8. Connect the coaxial cable from the detector to the remote shutdown (Inhibit) connection on the HVPS.
9. Connect the flat data transmission cable from the ADC to input 1 of the AIM. (Repeat steps 4 through 8 to connect a second detector to input 2 of the AIM).
10. Connect the output of the AIM to the Ethernet Cable using a transceiver cable.
11. Connect the Ethernet Cable to the local area network (LAN) Adapter on the desktop PC.

3.2 FILLING DETECTOR WITH LIQUID NITROGEN

This section describes how to transfer liquid nitrogen (LN_2) from the large tank to the HPGe detector. Note that LN_2 has a temperature of 77°K and extreme caution should be used when handling this chemical. Large (150 liters) tanks of LN_2 are ordered from LN_2 suppliers and last approximately 3 weeks. Detector dewar containers should be filled weekly. Failure to fill the dewars will cause the high voltage power supply to shut off. Liquid nitrogen, once transferred from the large tank to the portable dewar requires two days for internal pressure to become sufficiently high to transfer the liquid nitrogen from the portable dewar to the detector dewar. The procedure to fill the 50 L portable dewar follows:

1. Remove liquid dispensing nozzle from dewar if attached.
2. Connect one end of the LN_2 transfer hose to the liquid draw nozzle of the large tank.
3. After tightening to finger tightness, tighten with the wrench slightly.
4. Connect other end of hose to liquid transfer nozzle of portable dewar. Tighten as above.
5. Relieve excess nitrogen gas pressure by opening both the gas nozzle and the liquid nozzle on the dewar by moving the levers clockwise to the "up" position.
6. Observe pressure gauge on the portable dewar, and open liquid valve on large tank when pressure reads 0 psi. Open valve fully, then turn valve back slightly.
7. Fill time is about 10 to 20 minutes. The loudness and pitch of the escaping gas (through vent) will decrease abruptly when the dewar is full. Do not over fill.
8. Quickly close valve on the main tank. Lift the hose so that all of the LN_2 drains into the portable dewar.
9. Close liquid intake valve on portable dewar and quickly loosen nut on dewar end of transfer hose.
10. Close gas exhaust valve on portable dewar. Remove hose from dewar.

Should the valve on the main tank freeze when attempting to close it, close the intake valve, then the gas exhaust valve on the portable dewar. As the hose returns to room temperature, liquid nitrogen in the hose will be driven back into the tank, and the tank valve should warm to the point that it will be possible to close it.

The procedure to transfer LN_2 from the portable dewar to the detector dewar is as follows:

1. Attach liquid dispensing nozzle to liquid nozzle of portable dewar. Tighten with wrench as above.
2. Move portable dewar to detector dewar.
3. Attach intake hose (loosely hanging) to dispensing nozzle and open liquid valve fully.
4. Close valve when liquid nitrogen begins to travel down and out of exhaust hose on detector dewar.

3.3 TURNING ON AND CONFIGURING NIM HARDWARE

This section describes briefly how to power up (or power down) the front-end electronic modules (NIMs) of the gamma spectrometer. Before removing or installing any hardware in the NIM bin, detectors must be in a powered-down state. The procedure to turn on the front-end electronics follows (additional details are found in the user manuals for the respective components):

1. The bias supply has a power switch separate from the master power switch for the NIM bin. All the NIMs save the bias supply are powered from the master power switch. Before turning on the NIM bin, make sure that the power switch for the bias supply (HVPS) is OFF. Suden surges of power into the detector preamp from the HVPS can cause damage to the field-effect transistor in the preamp. Turn on the master power switch. After first making sure that the potentiometer on the HVPS is set to zero, turn on power to the HVPS. Allow 1 hour for the NIMs to warm up and stabilize.
2. Apply bias to the detector by rotating the potentiometer (pot) on the HVPS clockwise at a rate of about 10 volts per second. After 1 kV is reached, the rate of increase can be raised to about 100 V/sec until the recommended voltage is reached (2500 V for ORTC1-25 or 4000 V for CANB1-25). Do not use a voltage setting higher than the recommended level. When the desired setting is attained, lock the high-voltage pot by sliding the small switch on the side of the pot clockwise.
3. On the ADC, set the conversion gain to 4K, corresponding to 4096 spectrum channels of memory, by manually adjusting the appropriate dial on the front of the ADC.
4. Set the **shaping time** on the AMP to the level desired (generally, this is the default setting recommended by the manufacturer: 4 microseconds on the Canberra 2025, 6 microseconds on the Ortec 572).

5. Optimize the pole/zero setting on the AMP. For the Canberra 2025, depress the **auto set** button while counting a standard. Note: Automatic pole/zero matching must be re-initialized after the AMP shaping time is changed, the AMP is connected to a different detector/pre-amp, and/or the NIM power is interrupted. For the Ortec 572, connect the AMP output to the input of an oscilloscope. Adjust the pole zero until the output signal appears to have a clean return to the baseline on the scope.
6. Set the upper-level discriminator (ULD) and lower-level discriminator (LLD) on the ADC to set the energy window size to be output to the MCA (i.e., 1 to 2048 keV). Use the **zero** control on the ADC to advance the entire energy spectrum in relation to channels.

The procedure to power down the detector and turn off the front-end electronics follow:

1. Power down the HVPS by slowly turning the voltage control dial counterclockwise until it reaches 0 kV. Allow the voltage indicator to fall to zero or near-zero.
2. Turn off the power switch to the HVPS.
3. Turn off the power switch to the NIM bin.

Note: there is a circuit breaker on the power cable leading to the rack which houses the NIM bin. In the event of a power failure in the building, the power to the unit stays off once power is restored to the building. If this occurs, reduce the potential on the HVPS to zero, then reset the circuit breaker. Raise the potential as in step 2 above (powering up the components).

3.4 STARTING OS/2 AND GENIE-PC SOFTWARE

This section describes how to turn on the PC, assuming that OS/2 Warp and all Genie-PC software are preinstalled.

To start the OS/2 Warp Version 2.1 operating system:

1. Turn on PC by pressing button on front of PC.
2. Wait for OS/2 Desktop to appear on screen (Figure 3-1).
3. If the PC is already on, but the screen is locked, type the password and press enter (optional).

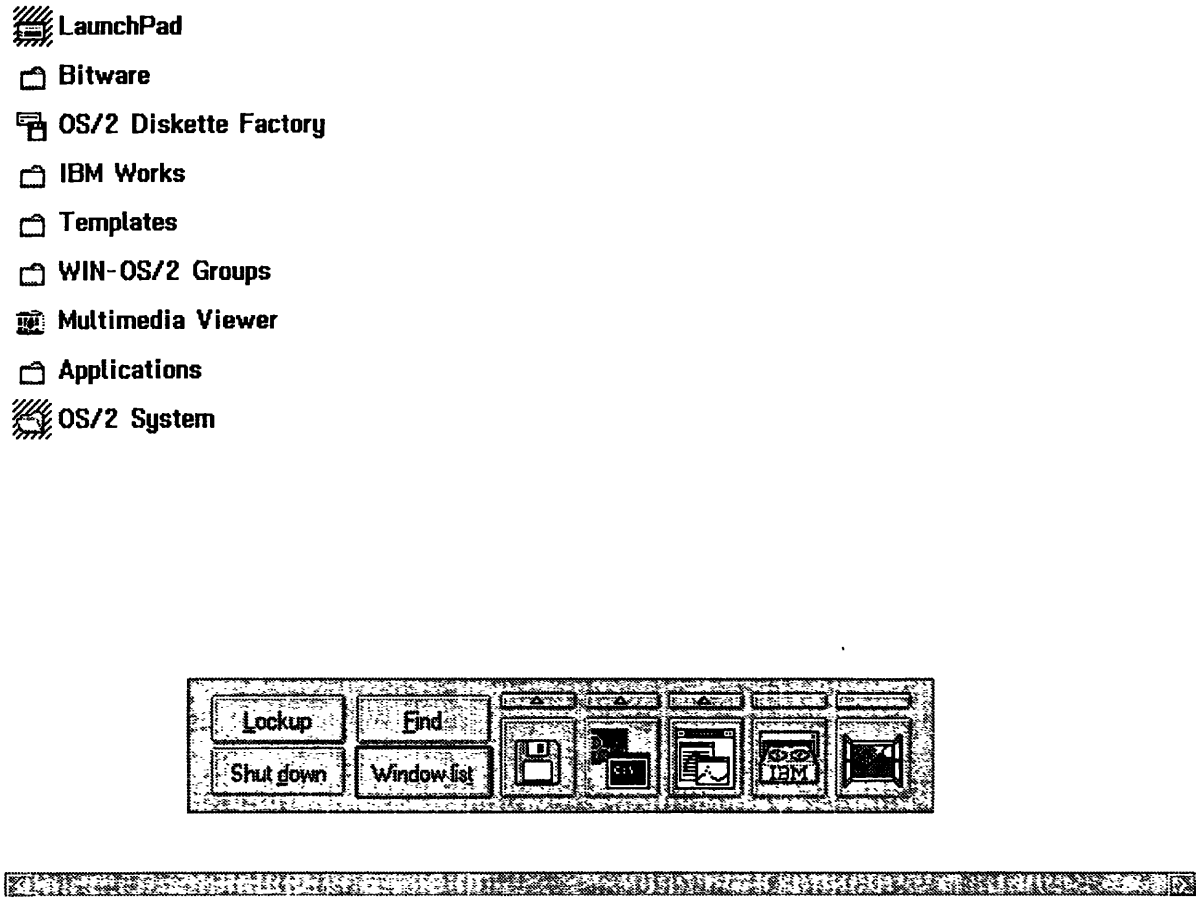


Figure 3-1. The Operating System/2 (OS/2) Desktop with Launch Pad.

To start Genie-PC spectroscopy software:

Prior to using any Genie-PC software, the Virtual Data Manager (VDM) must be running. Select **Window List** on the Launch Pad or press **Ctrl** and **Escape** to view active applications. The VDM should be on the list, if the VDM is not present, then it can be started by following this procedure:

1. Open the Genie-PC Program Group.
2. Open the VDM icon to start the program (Figure 3-2).
3. Place a copy of the VDM in the OS/2 system start up folder.

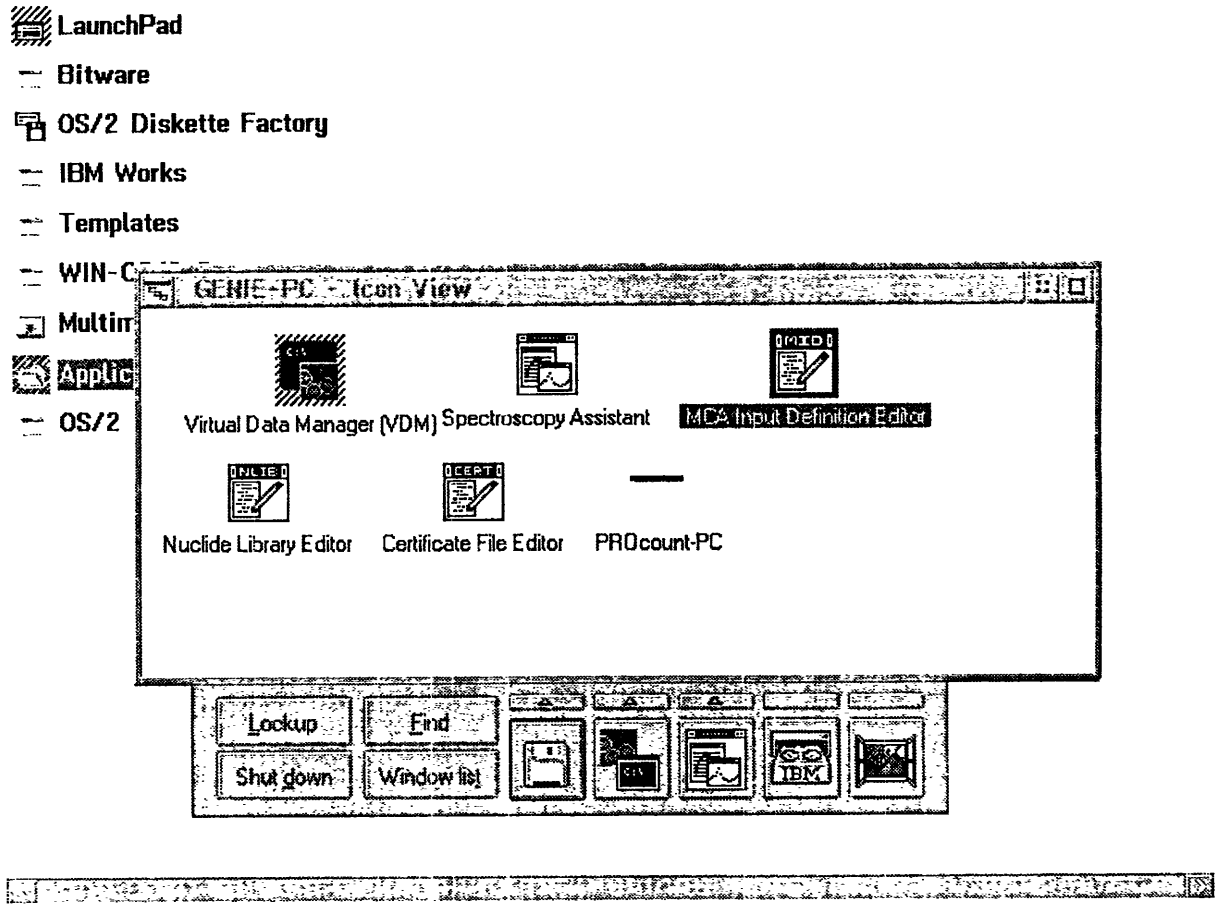


Figure 3-2. The Genie-PC icon Group.

After activating the VDM, any or all of the Genie-PC applications can be started.

To start the Spectroscopy Assistant (SA)

1. Select **SA** on the Launch Pad.

To start the Certificate File Editor (CERT)

1. Select **CERT** on the Launch Pad.

To start the MCA Input Definition Editor (MID)

1. Select **MID** on the Launch Pad.

To start the Nuclide Library Editor (NLIB)

1. Select **NLIB** on the Launch Pad.

3.5 MCA INPUT DEFINITION

The MCA Input Definition (MID) Editor is used to define the acquisition interface module (AIM) installed on the network and its associated detectors and front end electronics. The definition includes the address of the AIM and the number and types of NIMs. Follow these procedures to define and load the AIM MCA:

1. Verify the VDM is running (refer to Section 3.4).
2. Select **MID** on the Launch Pad.
3. Select **Edit** and choose **Add MCA.**
4. Select **AIM** under **Available MCAs** menu, select **Add** and then select **Ok**
5. Select **MCA** under **Device** menu. Set the following parameters:

   MCA full memory: **8k**
   Number of ADCs: **2**
   MCA station address: **740**

6. Select **Input** under **Settings** menu. Type the name of the detector (i.e., **ORTC1-25** or **CANB1-25**).
7. Select **Manual** under **Device** menu for ADC, HVPS, and AMP. (Repeat step 6 and 7 for each detector/AIM MCA)
8. Select **Save as** under **File** menu to save MID.
9. Select **Load to** under **Database** menu to load the AIM MCA to the database.
10. Exit.

These procedures do not need to be completed if the MID database has already been loaded. To check:

1. Select **View** under **Database** menu.
2. An MID definition should appear in the **MID Definition Table** as shown in Figure 3-3.
3. Select **Ok.**

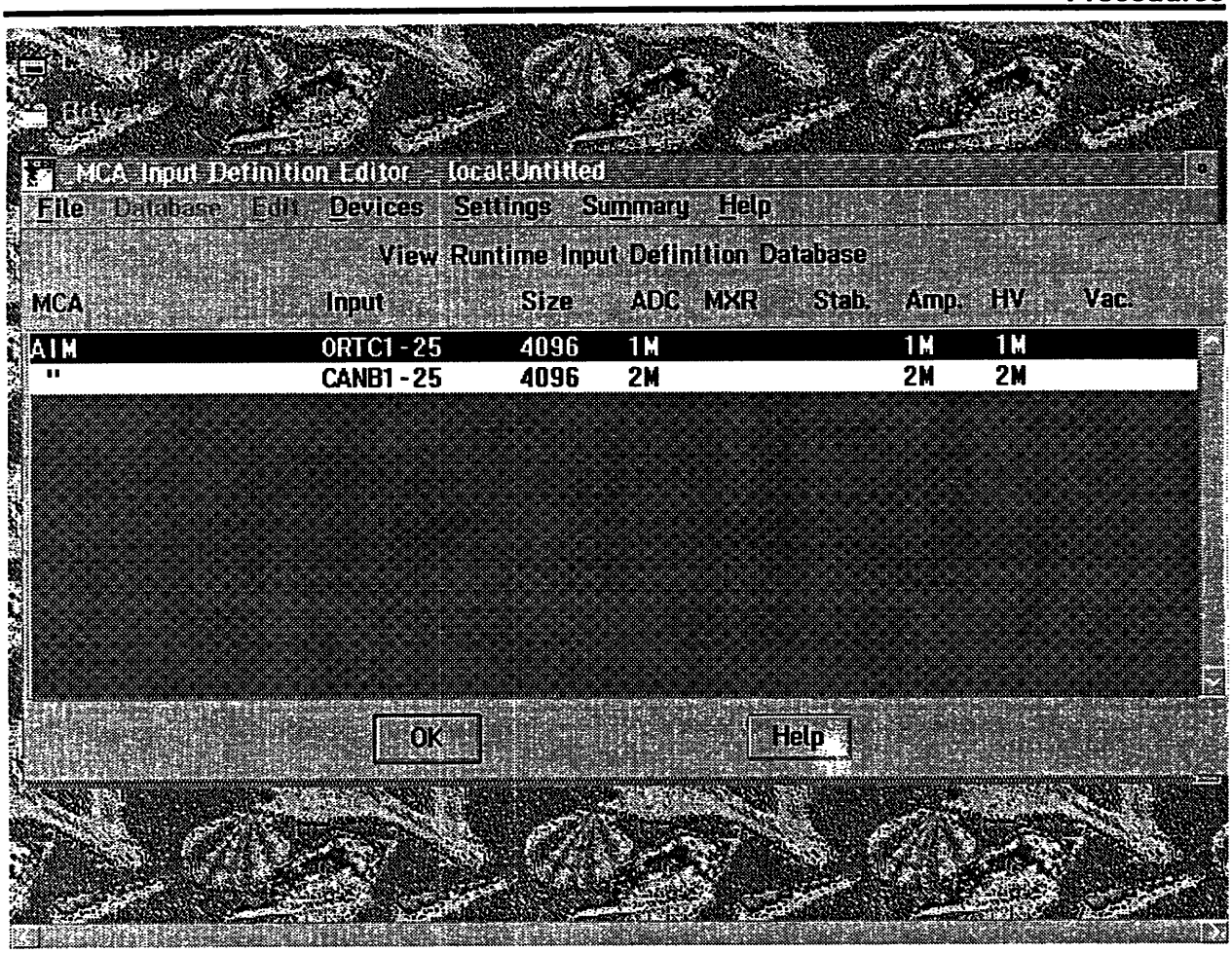


Figure 3-3. The MCA Input Definition (MID) Editor

3.6 CREATION OF CERTIFICATE FILES

This section describes how to create a certificate file using the Genie-PC Certificate File Editor. The certificate files reside on the hard drive of the PC and contain information about an analytical standard (nuclide half-life and activity) that is used for energy and/or efficiency calibration of the detector. These analytical standards represent the most common counting geometries employed in the PPRP radioecology laboratory. It should be noted that geometries are specific to size, shape, and density of samples and a certificate file needs to be created for each. Official certificates of calibration for each manufactured standard are maintained on file in the laboratory.

The directions for creating a certificate file and transferring data from the manufacturer's official certificate are as follows:

1. Verify the VDM is running (refer to Section 3.4).

2. Select **CERT** on the Launch Pad.
3. Enter **Header Data** in the CERT window.

   The header data includes:

   Title such as (C1-LIQ1L, C1-LIQ2L, or O1-SAN2L)
   Quantity (volume or mass) of the standard used in efficiency calculations.
   Assay Date from the certificate of calibration which came with the source.

4. Enter the **Line Data** into the parameter entry window.

   The line data includes:

   Nuclide name which is present in the gamma standard.

   Energy of the nuclide line, expressed in keV.

   Emission Rate in gammas per second (gps/Unit) of that line at the time the source was originally assayed.

   Rate Uncertainty in the emission rate, expressed as percent.

   Half-Life of the nuclide, which can be expressed in years, days, hours, minutes or seconds.

   Uncertainty of that half-life.

   (Repeat step 3 for each radionuclide in the mixed-gamma standard)

5. Select **Save** or **Save as** to save file.
6. Exit.

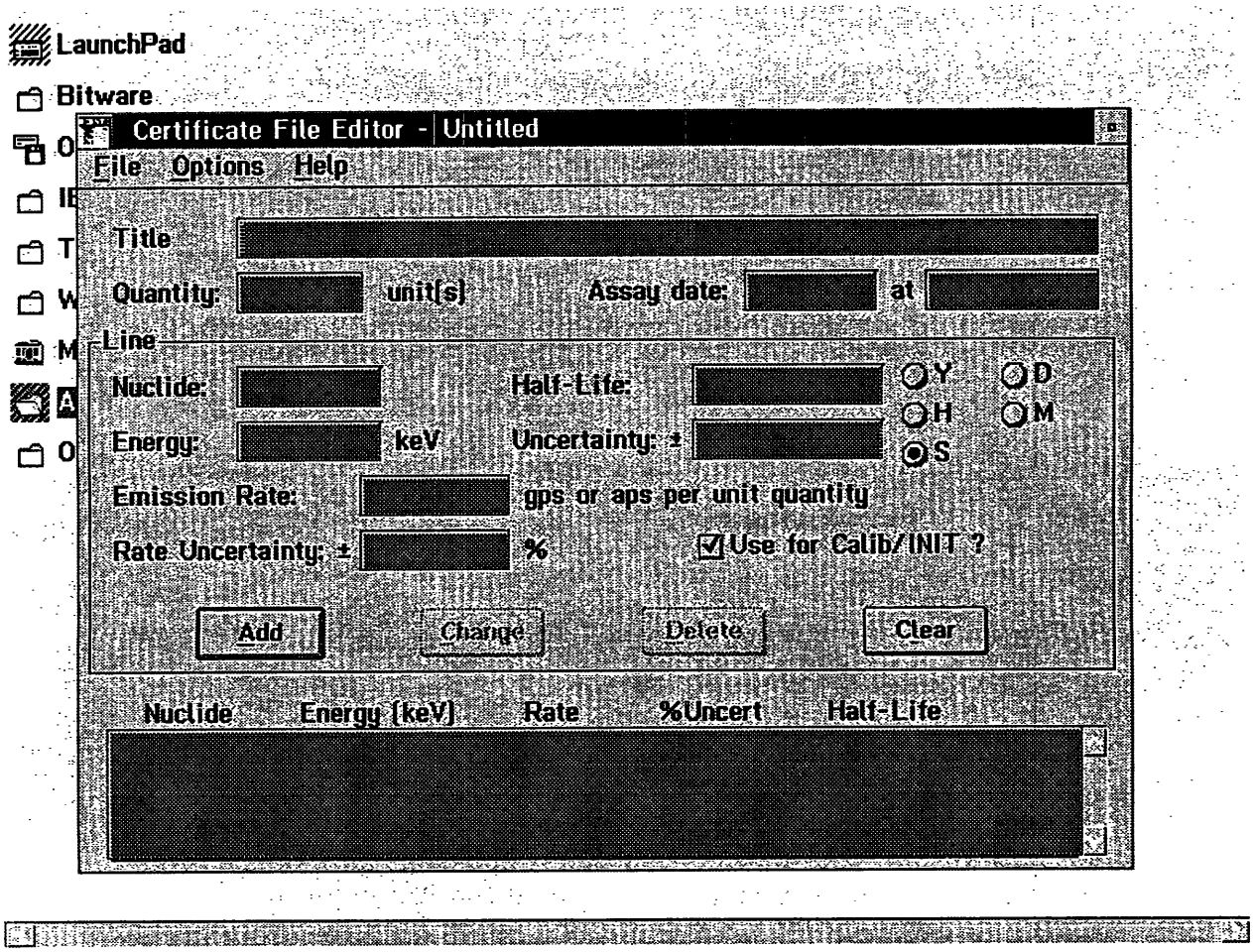


Figure 3-4. The Certificate File Editor (CERT)

3.7 SPECTROMETER ENERGY CALIBRATION

Energy calibrations are performed periodically to compensate for instrument drift. The calibration should be performed monthly, or whenever a peak drift is apparent by observing peak energies in analytical results (see Section 3.13). In the energy calibration process, a linear relationship is established between known photopeak energy levels and the channel numbers in the MCA in which they fall. The source being used for energy calibration should be counted for an amount of time sufficient for all of the peaks in the standard to have a net area of 20,000 counts (Canberra 1995). The methods for calibrating the spectrometer are as follows:

1. Verify the VDM is running (refer to Section 3.4).
2. Select **SA** on the Launch Pad.
3. Choose the **MCA View Control** (MVC) command in the **Applications** menu to add the MVC application to the workspace.

4. Count a gamma standard for at least 2 hours and save the raw spectrum (Section 3.10).
5. Choose the **Gamma Spectroscopy Analysis** (GSA) command in the **Applications** menu to add the analysis application to the workspace.
6. Select **Arrange Tiled** or **Arrange Cascaded** under SA windows menu to arrange the workspace.
7. Select **Open datasource** under the **File** menu of the GSA window to choose the data to be used for the calibration.
8. Select **Detector** in the Open Datasource dialog box. Choose the specific detector (ORTC1-25 or CANB1-25) to be opened in the MVC window. Execution status should read **ready** if the datasource was opened correctly.
9. Select **Energy Full** under **Calibrate** menu (Figure 3-5).
10. Select **Populate** and open certificate file created in Section 3.6. A menu listing the certificate files in the C:\GENIEPC\CAMFILES directory will appear.
11. Select **Auto** — each energy line in the certificate is located in the spectra and measured.
12. Select **Show** to view the Energy Calibration Curve (keV vs. channel). Select **+-** to increase or decrease the polynomial equation which best fits the measured data points.
13. Select **Ok** to accept the energy calibration.

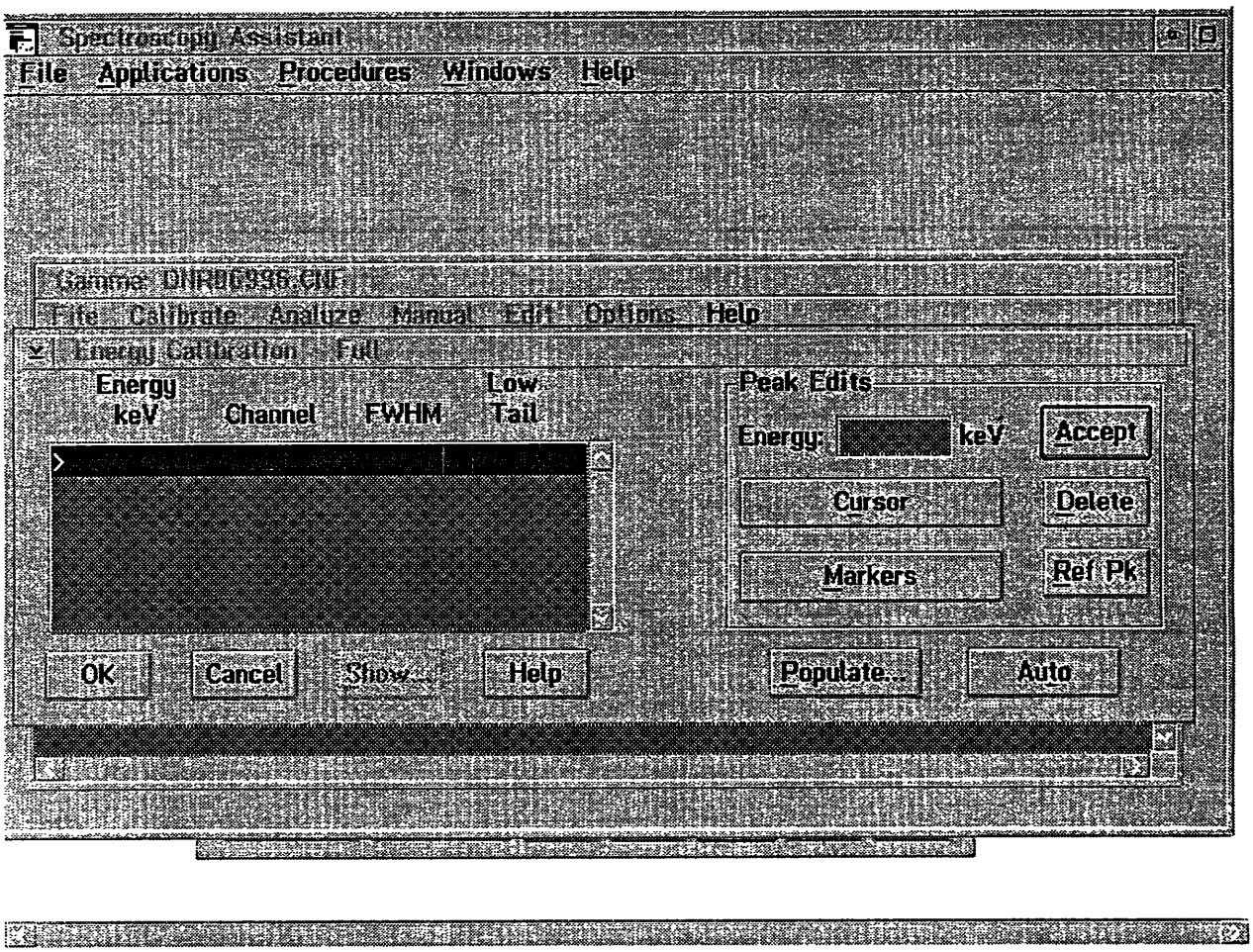


Figure 3-5. The Calibration store menu

3.8 EFFICIENCY CALIBRATION AND CREATION OF EFFICIENCY FILES

For each geometry and detector used by the gamma spectrometer system, an efficiency calibration must be performed. The efficiency calibration establishes a relationship between the count rate registered by the counting equipment and the actual gamma emission rate of nuclides in the sample. Efficiency varies over the range of photopeak energies measurable by the detector, so it is important to select a standard which produces a mix of gamma energies over the entire spectral range. The efficiency calibrations of the various geometries and detectors are stored on the hard drive as efficiency files, which are loaded when sample spectral data is processed.

Efficiency calibrations should be performed biennially, or when hardware changes (i.e., settings, detector, or NIMs) to the spectrometer occur. The procedures for efficiency calibration and creating efficiency files are as follows:

1. Verify the VDM is running (refer to Section 3.4).
2. Select **SA** on the Launch Pad.
3. Choose the **MCA View Control** (MVC) command in the **Applications** menu to add the MVC application to the workspace (Figure 3-6).
4. Count a gamma standard for 1000 minutes and save the raw spectrum (Section 3.10).
5. Choose the **Gamma Spectroscopy Analysis** (GSA) command in the **Applications** menu to add the analysis application to the workspace.
6. Select **Arrange Tiled** or **Arrange Cascaded** under SA windows menu to arrange the workspace.
7. Select **Open datasource** under the **File** menu of the GSA window to choose the data to be used for the creation of an efficiency file.
8. Select **Detector** in the Open Datasource dialog box. Choose the specific detector (ORTC1-25 or CANB1-25) with the raw spectra acquired in step 4. Execution status should read **ready** if the datasource was opened correctly.
9. Select **Efficiency** under **Calibrate** menu (Figure 3-7)
10. Select **Populate** and open certificate file created in Section 3.5. A menu listing the certificate files in the C:\GENIEPC\CAMFILES directory will appear.
11. Select Auto — efficiencies of each energy line listed in the certificate file are measured in the spectrum.
12. Select **Show** to view the calibration curve as a function of energy. Select **+-** to increase or decrease the polynomial equation which best fits the measured data points.
13. Select **Ok** to accept the efficiency calibration.
14. Select **Store** under **Calibrate** menu to save the efficiency file. Enter the information in the format provided in the following example:

Filename:	O1LIQ1L.CAL
Calibration description:	Analytics Standard 1996
Directory:	C:\GENIEPC\CALFILES
Efficiency geometry ID:	1LMAR

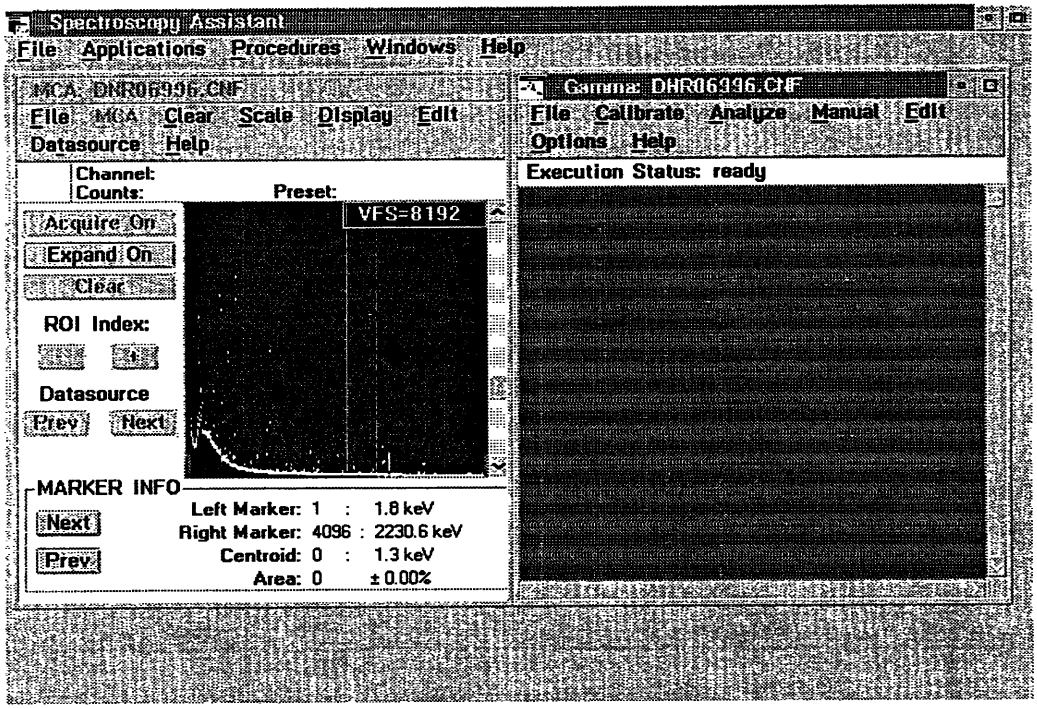


Figure 3-6. The Spectroscopy Assistant Window with a MCA View Control (MVC) window added

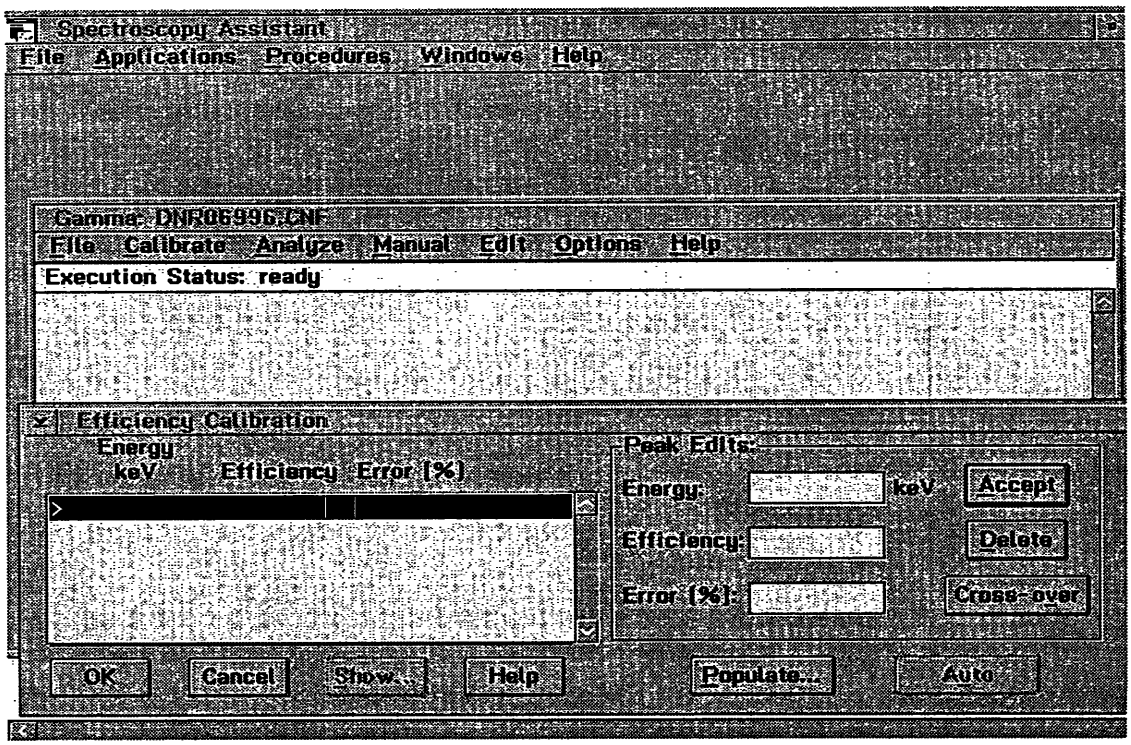


Figure 3-7. The Efficiency Calibration menu

3.9 PREPARING A RADIONUCLIDE LIBRARY

This section describes how to use the Genie-PC Nuclide Library Editor (NLIB) to modify existing and create new nuclide libraries. The spectral processing software refers to a library, or list of radionuclides which might contribute to the spectra. For every radionuclide in the library, the following parameters are listed: half-lives, gamma energies, and the abundance of these energy lines. Radionuclides included in the library are chosen based on a knowledge of background activities and previously identified radio activities in samples. It is important to note that the spectral processing software cannot identify nuclides that are not listed in the library. The procedures to create or edit a nuclide library using the NLIB follow:

1. Verify the VDM is running (refer to Section 3.4).
2. Select the **NLIB** on the Launch Pad (Figure 3-8).
3. Select **Open** in the **File** menu to edit an existing file.
4. Enter **Basic Nuclide Data** in the library opened for editing.

   The basic nuclide data fields include:

   Name of the nuclide

   Type or classification of the nuclide (i.e., natural, fission, or activation product)

   Half-Life of the nuclide. Choose time units: years, days, hours, minutes or seconds.

   Uncertainty of the half-life expressed in the same units as the half-life. Note: The assumption is made that the activity levels for daughter nuclides in the decay chains for primordial elements (^{238}U, ^{235}U, ^{232}Th) are in secular equilibrium; therefore, the half-life for these nuclides is set to 100,000 years.
5. Select **Add Nuclide** to add the new information to the library.
6. Select **Clear** button to clear edit boxes so that new values can be entered.
7. Select **Change** to edit an existing nuclide entry.
8. Edit the **Energy Line Data** in the library opened for editing.

   The energy line data fields include:

   Energy is the energy of the line (keV).

   Uncertainty in the energy, expressed in same units as energy.

   Abundance is the ratio of gamma-rays emitted at a specific energy to disintegrations. Abundance is also called branching ratio or yield.

Uncertainty in the abundance, expressed in absolute terms.

Key Line is the energy from which the activity will be calculated if a weighted mean of all the activities of the nuclide is not to be calculated.

9. Select **Add Line** to add a new line to the nuclide.
10. Select **Delete** to delete a line from a nuclide.
11. Select **Extract** from the Options menu to extract nuclides and their associated energy lines and information from a master nuclide library file.
12. Be sure to **Save** the nuclide library after completing the edits.

The master libraries that are included with the Genie-PC software contain about 800 nuclides and 31,000 energy lines and were obtained from a database maintained by the National Nuclear Data Center of the Brookhaven National Laboratory. These master libraries, named A_G.NLB, H_O.NLB, P_R.NLB, and S_Z.NLB, contain nuclides with names starting with letters A through G, H through O, P through R, and S through Z, respectively.

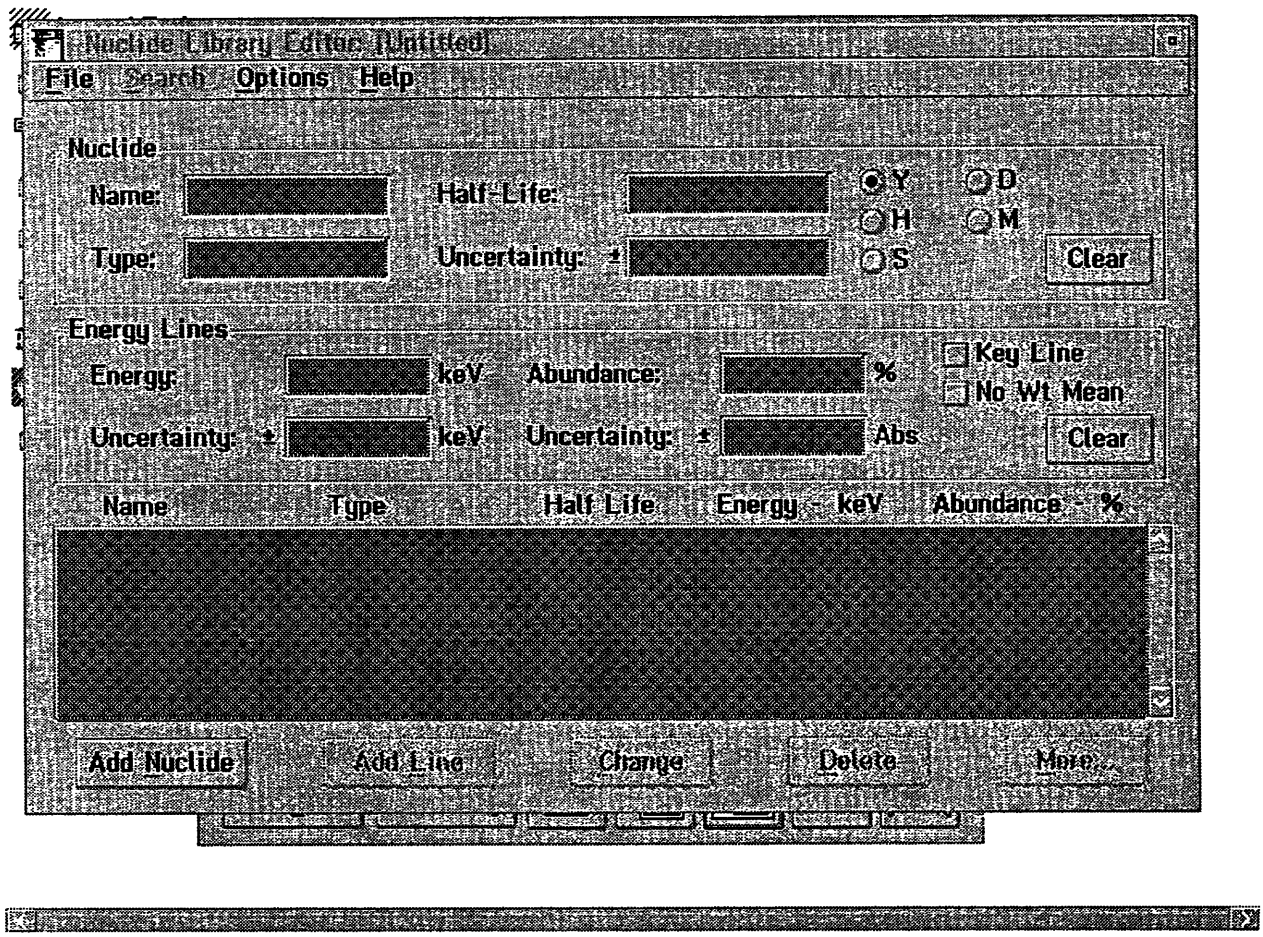


Figure 3-8. The Nuclide Library Editor (NLIB)

3.10 COUNTING A SAMPLE (BASIC DAILY OPERATIONS)

This section describes how to count a sample using the Genie-PC Spectroscopy Assistant (SA) data acquisition software. Before starting acquisition, the VDM must be running. The SA is a Presentation Manager application into which spectroscopy applications can be placed in order to run experiments. The MVC is opened in the SA to both initiate and view data acquisition. However, prior to the commencement of data acquisition one of the MCAs connecting the detector to the PC needs to be selected. Currently the two MCAs in the radioecology laboratory are distinguished by the identification code of the detector to which they are connected. The codes are: ORTC1-25 and CANB1-25. The procedures to begin acquisition of data follow:

1. Verify the VDM is running (Section 3.4).
2. Select **SA** on the Launch Pad
3. Choose the **MCA View Control** (MVC) command in the **Applications** menu to add the MVC application to the workspace. The MVC enables the user to view the data while acquiring it. Open two MVC applications into the workspace, one for each detector and MCA (Figure 3-9).
4. Select **Arrange Tiled** or **Arrange Cascaded** under Window menu to arrange the workspace.
5. Select **Open Datasource** under the **File** menu to choose the source of the data to be used with the MVC.
6. Select **Detector** in the Open Datasource dialog box. Choose the specific detector (ORTC1-25 or CANB1-25) to be opened in the MVC window. Execution status should read **ready** if the datasource was opened correctly.
7. Select **Clear** to remove existing spectrum in the MVC window.
8. Select **Acquire Setup** and set count time, typically 1000 minutes.
9. Select **Edit sample information** under **Edit** menu (Section 3.11.2). The dialog box allows the user to add to the data file a description of the data and sample that was acquired.
10. View **Status** at the far left of the MVC's status line. It should read Idle, indicating a sample is not being counted.
11. Select **Acquire on** (the raw spectral data should appear in the MVC window)
12. View **Status**, it should say **Busy** in place of the word Idle. When the preset count time has been reached (i.e., the acquisition is complete) the status should say **Done.**
13. Once the data has been collected, select **Save** or **Save as** to save the spectrum.
14. Select the 'ARCHIVES' subdirectory and type the file name in the format (DNRXXXXX.CNF)

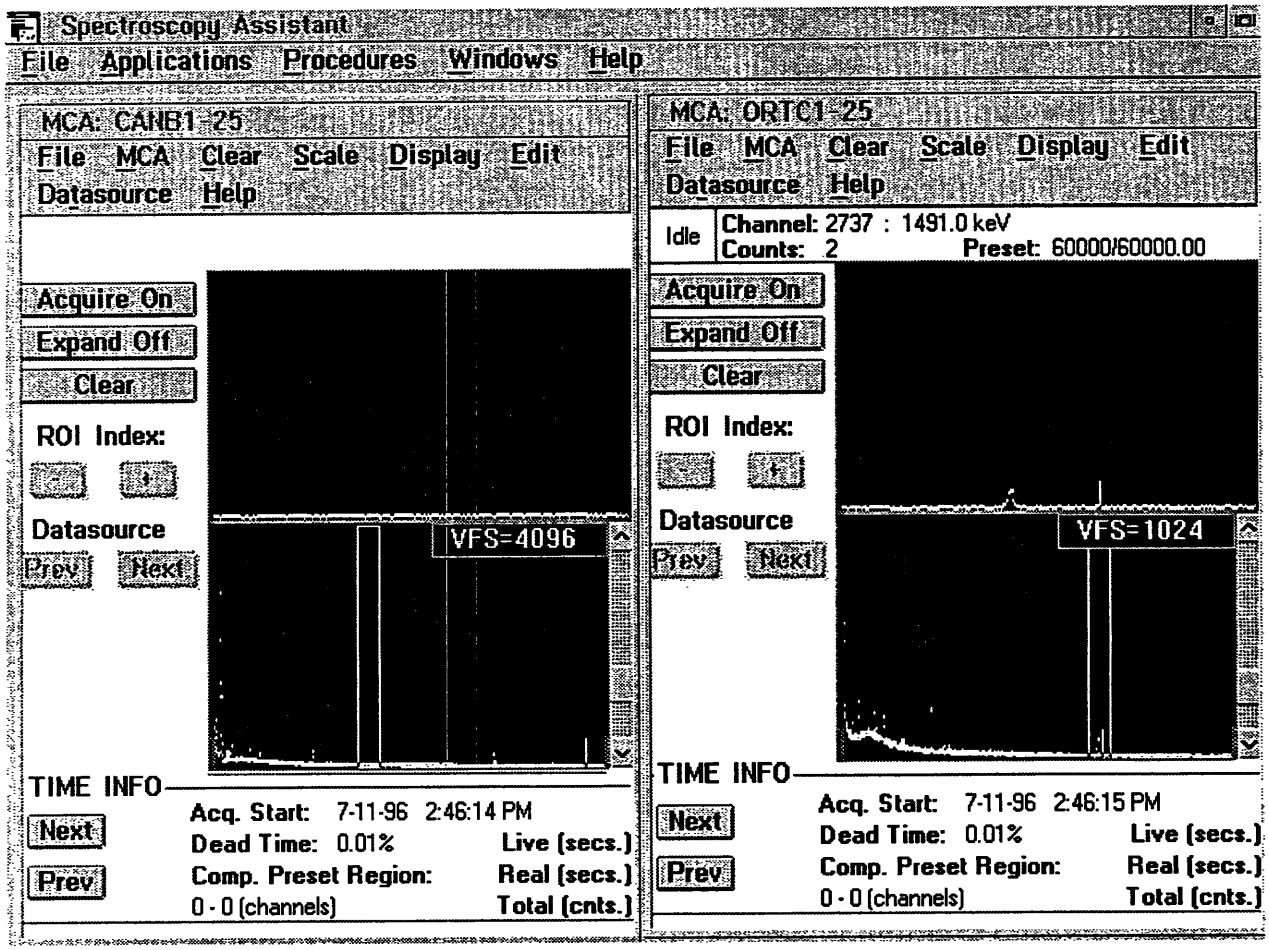


Figure 3-9. The Spectroscopy Assistant Window with two MCA View Controls added

3.11 DATA ENTRY

This section describes where to enter data elements. The two locations to enter radioecology data include a spreadsheet file created in Quattro Pro and a parameter entry window in the Genie-PC data acquisition and spectrum processing software. A description of the valid codes to be entered in the spreadsheet sample log and Genie-PC are outlined in the Documentation for the PPRP radioecology data base (Frithsen et al. 1996). All the data generated by the laboratory are appropriately verified to minimize data entry errors, and verified against valid entries before being saved electronically and transferred to the SAS data base.

3.11.1 Preparing the Spreadsheet Sample Log

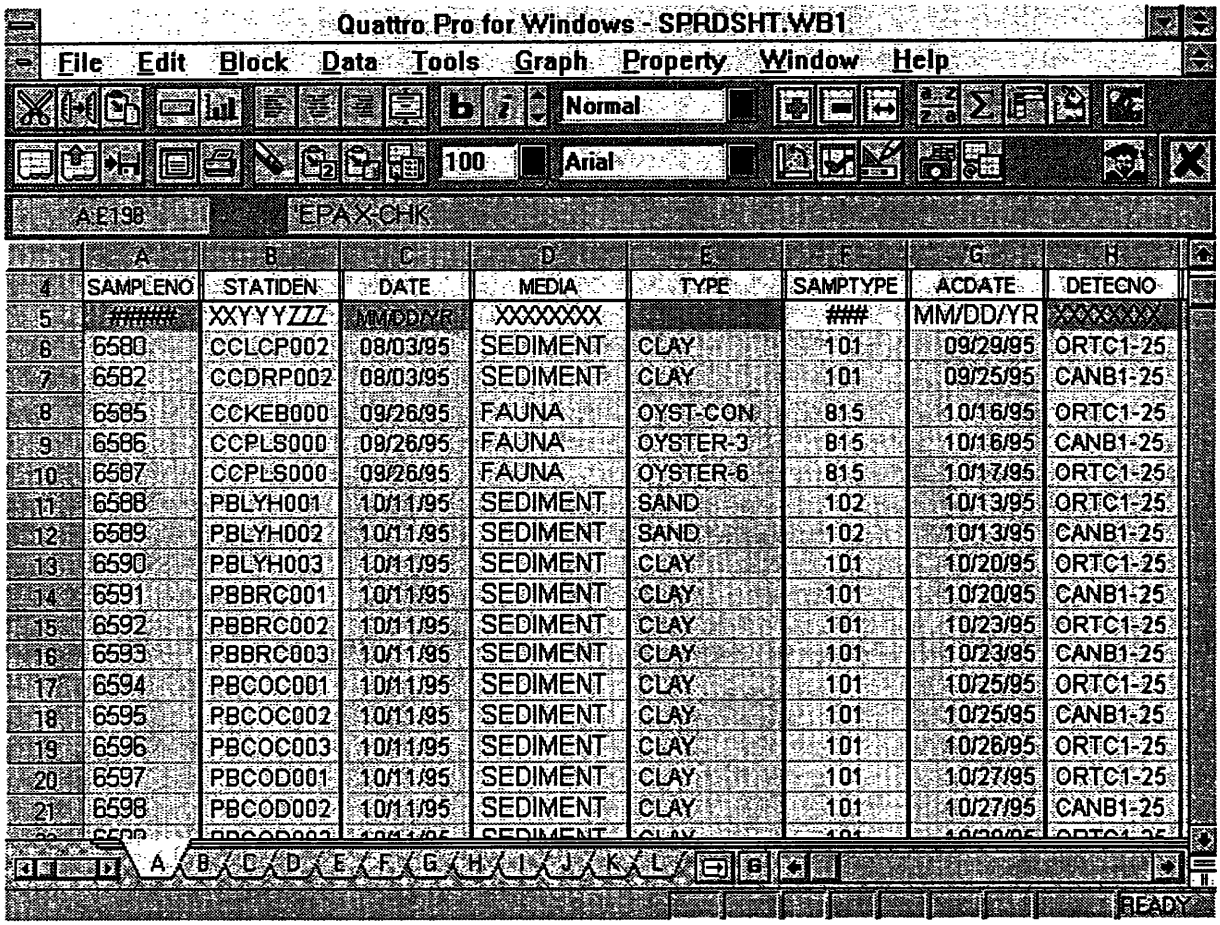
The electronic sample log contains descriptive information about the environmental samples and standards analyzed as part of radionuclide monitoring activities. Information recorded in a field notebook pertaining to conditions at specific sample locations and relating to specific samples is entered into the spreadsheet. Data entry of information related to environmental samples occurs both before and after field sampling. The sample log contains the data set elements listed in Table 3-1.

Table 3-1. Data elements comprising the spreadsheet sample log

Data elements provided prior to the initiation of sample collection	Data elements provided following sample collection
Sample Number	Sample Collection Time
Station Identification Code	Sample Collection Depth
Sample Collection Date	Dissolved Oxygen
Sample Status	pH
Sample Media	Salinity
Sample Type	Temperature
Sample Method	Seston
Taxonomic Group	Chlorophyll
	Age or Ageclass
	Sample Size
	Sample Size Unit
	Sample Volume
	Sample Wet Weight
	Sample Dry Weight
	Sample AFD
	Exposure Period
	Efficiency/Calibration File Name
	Spectrum File Name
	Results File Name
	Replicate Analysis

The procedures to enter sample information into the spreadsheet sample log follow:

1. Select **Windows** on the Launch Pad.
2. Open **Quattro Pro.**
3. Open the file C:\ABC\SAMP_LOG.WB1 (Figure 3-10).
4. Enter data elements in the appropriate fields.
5. Save file and exit Quattro Pro



	A	B	C	D	E	F	G	H
4	SAMPLENO	STATIDEN	DATE	MEDIA	TYPE	SAMPTYPE	ACDATE	DETECNO
5	######	XXYYYZZZ	MMDDYR	XXXXXXX		###	MM/DD/YR	XXXXXXX
6	6580	CCLCP002	08/03/95	SEDIMENT	CLAY	101	09/29/95	ORTC1-25
7	6582	CCDRP002	08/03/95	SEDIMENT	CLAY	101	09/25/95	CANB1-25
8	6585	CCKEB000	09/26/95	FAUNA	OYST-CON	815	10/16/95	ORTC1-25
9	6586	CCPLS000	09/26/95	FAUNA	OYSTER-3	815	10/16/95	CANB1-25
10	6587	CCPLS000	09/26/95	FAUNA	OYSTER-6	815	10/17/95	ORTC1-25
11	6588	PBLYH001	10/11/95	SEDIMENT	SAND	102	10/13/95	ORTC1-25
12	6589	PBLYH002	10/11/95	SEDIMENT	SAND	102	10/13/95	CANB1-25
13	6590	PBLYH003	10/11/95	SEDIMENT	CLAY	101	10/20/95	ORTC1-25
14	6591	PBBRC001	10/11/95	SEDIMENT	CLAY	101	10/20/95	CANB1-25
15	6592	PBBRC002	10/11/95	SEDIMENT	CLAY	101	10/23/95	ORTC1-25
16	6593	PBBRC003	10/11/95	SEDIMENT	CLAY	101	10/23/95	CANB1-25
17	6594	PBCOC001	10/11/95	SEDIMENT	CLAY	101	10/25/95	ORTC1-25
18	6595	PBCOC002	10/11/95	SEDIMENT	CLAY	101	10/25/95	CANB1-25
19	6596	PBCOC003	10/11/95	SEDIMENT	CLAY	101	10/26/95	ORTC1-25
20	6597	PBCOD001	10/11/95	SEDIMENT	CLAY	101	10/27/95	ORTC1-25
21	6598	PBCOD002	10/11/95	SEDIMENT	CLAY	101	10/27/95	CANB1-25

Figure 3-10. The Spreadsheet Sample Log

3.11.2 Genie-PC Spectrum Acquisition and Processing Software

Data entry of information related to sample counting begins prior to acquisition, however may continue until spectrum processing is initiated. The analysis of environmental samples to determine radionuclide concentrations is completed in two steps. First, a gamma spectrum must be acquired (refer to Section 3.10). The commencement of acquisition requires the reentry of sample number, collection date, and the efficiency/calibration file. Reentry of sample number and collection date is necessary in order to link the sample log to the spectrum processing ASCII files. The other data elements entered prior to the commencement of spectrum processing (in the Genie-PC parameter entry fields window) are listed in Table 3-2. The procedure for entering this information follows:

1. Open SA, MVC, and datasource (Section 3.10).
2. Select **Edit sample information** under **Edit** menu (Figure 3-11).

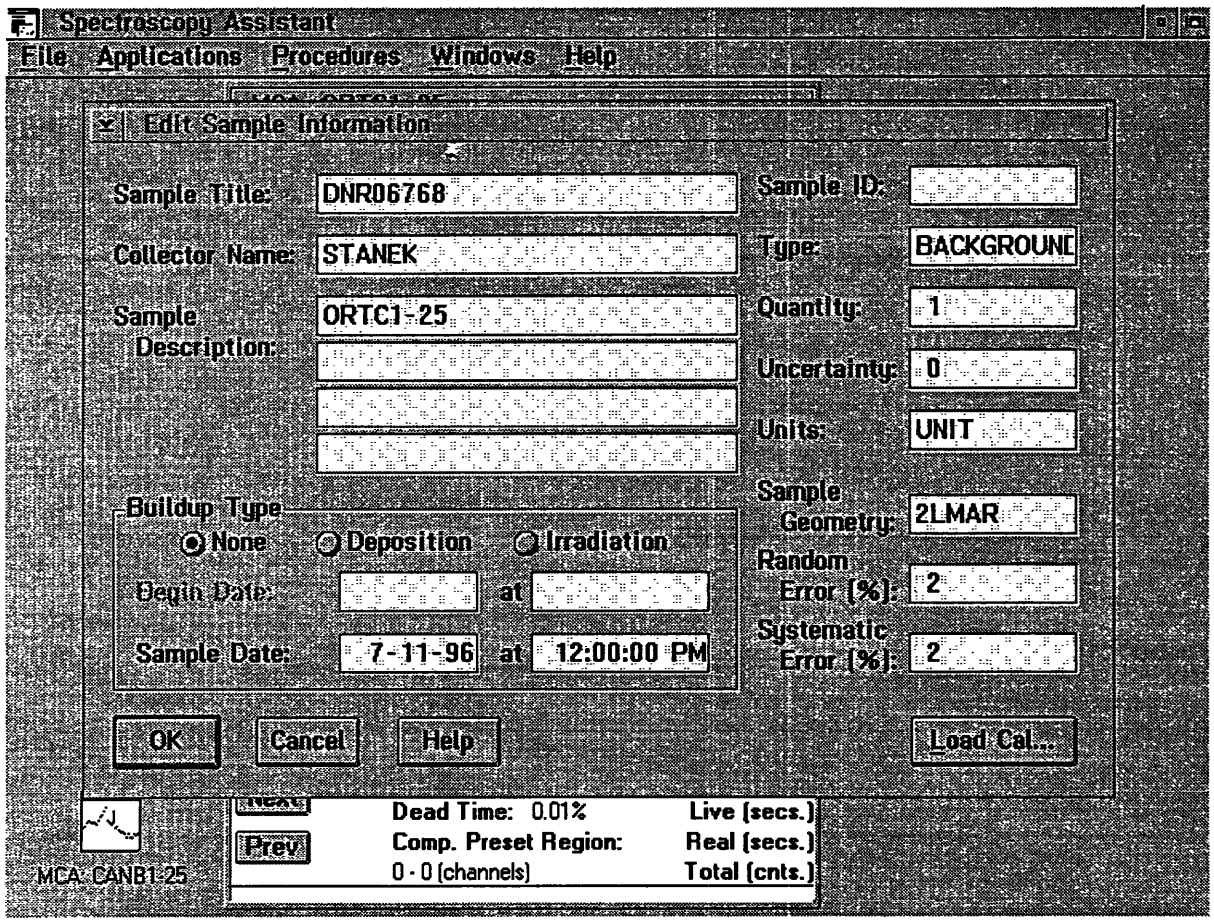


Figure 3-11. Edit Sample Information Dialog Box.

Table 3-2. Data elements provided at the commencement of spectrum acquisition	
Sample Collection Date (Sample Date)	Sample Geometry (Sample Geometry)
Replicate Analysis (Sample Title)	Efficiency/Calibration File Name [a]
Sample Counting Time (see Section 3.9)	Quantity [b]
Sample Collection Time (Sample Time)	Random Error (user defined random error)
Sample Number (Sample Title)	Systematic Error (user defined systematic error)

[a] Select **Load Calibration** and choose the appropriate field (Figure 3-12).
[b] A value of 1 is entered. Sample weights are entered into the spreadsheet sample log. Concentrations and counting errors of radionuclides are adjusted for the weight of the sample using SAS programs prior to analysis and reporting.

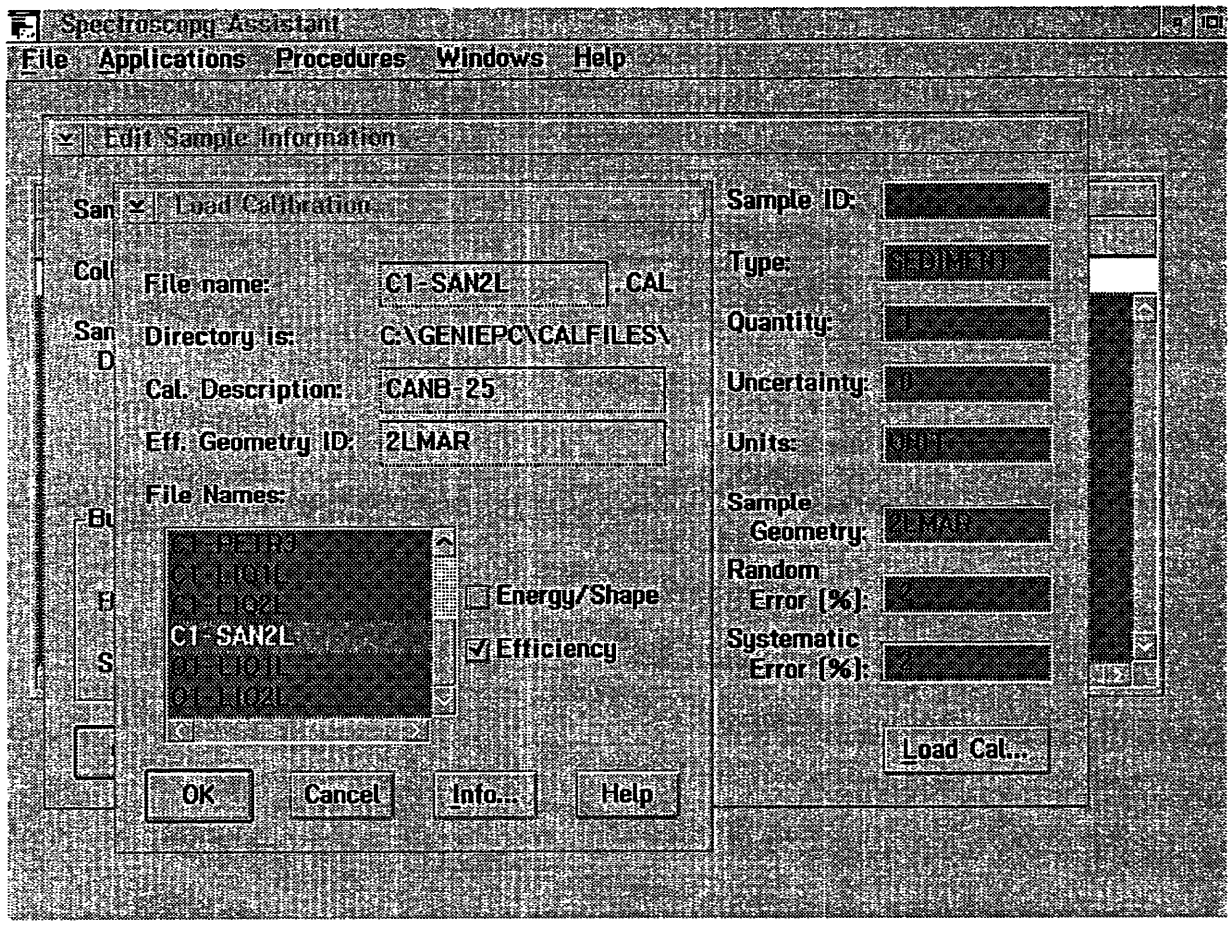


Figure 3-12. Menu of Calibration Files

3.12 PROCESSING A SPECTRUM

This section describes how to use the Gamma Spectroscopy Analysis (GSA) application to analyze and generate reports on spectral data collected with the MCA View Control application. The radionuclides present in a sample are identified and quantified by initiating an analysis sequence on raw spectral data. The sequence file includes analysis algorithms which have been customized to generate the desired output. The data elements provided during spectrum processing are listed in Table 3-3. The steps to initiate an analysis sequence file on raw spectral data include:

1. Verify the VDM is running (refer to Section 3.4).
2. Select **SA** on the Launch Pad
3. Choose **the Gamma Spectroscopy Analysis** (GSA) command in the **Applications** menu to add the analysis application to the workspace.
4. Select **Open Datasource** under the **File** menu to choose the spectrum to be processed. Raw spectral files are stored in C:\GENIEPC\ARCHIVES.

5. Select **Output to Versar** under the **Analyze** menu to initiate the analysis sequence. A copy of the spectral processing results will appear in the display area of the GSA window and in C:\GENIEPC\REPFILES.
6. Review the processed spectrum results.

Table 3-3. Data elements provided by spectrum processing output

Counting Date	Counting Error Per Sample
Detector Identification Code	Nuclide
Radionuclide Library	Minimum Detectable Activity
Activity Per Sample	

A copy of the ACII spectrum results file goes to both the screen and a file. Invalid data entry, energy or efficiency calibration will likely terminate the analysis sequence. In case of errors refer to source material. Appendix A illustrates the ASCII output generated by the spectrum processing analysis sequence called **Output to Versar**.

3.13 RESULTS VERIFICATION

Once spectral processing is complete, it is important to validate the data by verifying known characteristics of each spectrum. Knowledge of the energies of major gamma-rays of a given isotope are essential. Confirm the gamma peaks are positioned in the proper energy channel. The gamma peaks present in a spectrum are largely dependent on the type of sample being counted. Even though a sediment sample spectrum may contain dozens of peaks, typically the ^{208}Tl — 583.1 keV peak and ^{40}K — 1460.8 keV peak are present.

In the review of processed spectrum results (Section 3-12), particular attention must be made to **interference corrected activity** which will list the nuclides identified and quantified in the sample, and **unidentified peaks** which lists the photopeaks for which Genie-PC could not match to photopeaks in the nuclide library used.

The **interference corrected activity** lists several nuclides and their activities, plus those nuclides which were deleted when the interference correction was performed. Deleted nuclides will have the letter 'X' placed before them in the report. Question marks are placed before two or more nuclides in the report if Genie-PC is unable to determine definitively which nuclide is responsible for the presence of a particular photopeak. It is the radioecologist's responsibility to decide which nuclide is most likely to exist in the sample. Use the OS/2 text editor to remove nuclides which have been deleted (those with the letter 'X') and to remove question marks and nuclides which have been determined not to exist in the sample.

The **unidentified peaks** report most likely shows primordial nuclide (^{238}U, ^{232}Th, ^{235}U) decay chain photopeaks which are not included in the nuclide library. Investigate these peaks by using

the appropriate reference materials. The report may indicate to the radioecologist that instrument drift has occurred. If peaks fall outside of the energy tolerance set in the nuclide identification step in the algorithm, Genie-PC will identify it inaccurately or not at all. A good indicator of peak drift is the appearance of the 1461 keV photopeak (K-40) and/or the 477 keV photopeak (Be-7) in the unidentified peak report. If this is the case, the spectrum processing algorithm must be edited and rerun. The suggested procedure is as follows:

1. Open SA, GSA window and file to be processed (Section 3.12).
2. Select **Analysis Sequence** under GSA **Edit** menu.
3. Select **Load**. A menu of analysis sequence descriptions will appear.
4. Open **Output to Versar**. A menu of eight analysis steps will appear. The steps include:

Reporting	Peak Locate
Peak Area	Efficiency Correction
Nuclide Identification	Detection Limits
Reporting	Reporting

5. Open Nuclide Identification (NID) step. Adjust the following parameters:

   Energy Tolerance: (increase the preset value of 0.80 keV)

   NID Confidence Threshold: (decrease the preset value of 0.30)

   Note: The minium change in energy tolerance and confidence threshold which will produce the desired result should be used.

6. Select **Ok**, then **Execute**. Updated analysis results will appear on the screen and in the C:\GENIEPC\REPFILES directory.

3.14 ARCHIVING RAW SPECTRA AND RESULTS

This section describes the frequency of storage and archival of radioecology data. The spreadsheet sample log is stored on the PC and archived on external media twice a month. The ASCII spectrum results files are also stored on the PC, but archived on external media to prevent accidental loss due to hardware failure or programming error weekly. The procedures to archive the spreadsheet sample log follow:

1. Open the spreadsheet sample log (see Section 3.10.1)
2. Insert floppy disk in drive A.
3. Select **SAVE AS** in the File menu.
4. Enter the location in the blank field.

The procedures to archive processed spectral data follows:

1. Verify the VDM is running (refer to Section 3.4)
2. Select **C:** (hard drive) on the Launch Pad. A file manager will appear on the screen.
3. Open **C:\GENIEPC\REPFILES**. Data is stored in the subdirectory called 96PCDATA.
4. Select files (DNRXXXXX.RPT) to be copied.
5. Press right mouse button and choose **Copy** command from menu.
6. Select **Copy**, name of file to be copied should appear highlighted.
7. Select **Drives**, choose **Drive A**.
8. Insert disk in **Drive A** and select **Copy**.

3.15 PREPARING DATA FOR TRANSFER TO SAS DATA SETS

Radioecology monitoring results are delivered to Versar for transfer to SAS data sets biannually. A program written in OS/2 REXX programming language is used to append all spectral reports generated by an analysis sequence. The procedure for appending report files follows:

1. Open **OS/2 Window**.
2. Open **C:\DATAMGT**.
3. Open **Append.cmd** icon. (Follow instructions which appear in the PMREXX window, Figure 3-13).
4. Enter type of spectral files to compress (i.e., **RPT** extension)
5. Enter subdirectory under **C:\GENIEPC\REPFILES** where files are located.
6. Enter name of compressed file. (Format **YRDATA#.RPT**) Note: the file will be stored under **C:\DATAMGT\ARCHIVES**.
7. Enter name of zipped file (format: **YRDATA#.ZIP**, where YR represents the calendar year, and # represents the data set transferred to SAS format for the year).
8. Exit the PMREXX window once the program has ended.

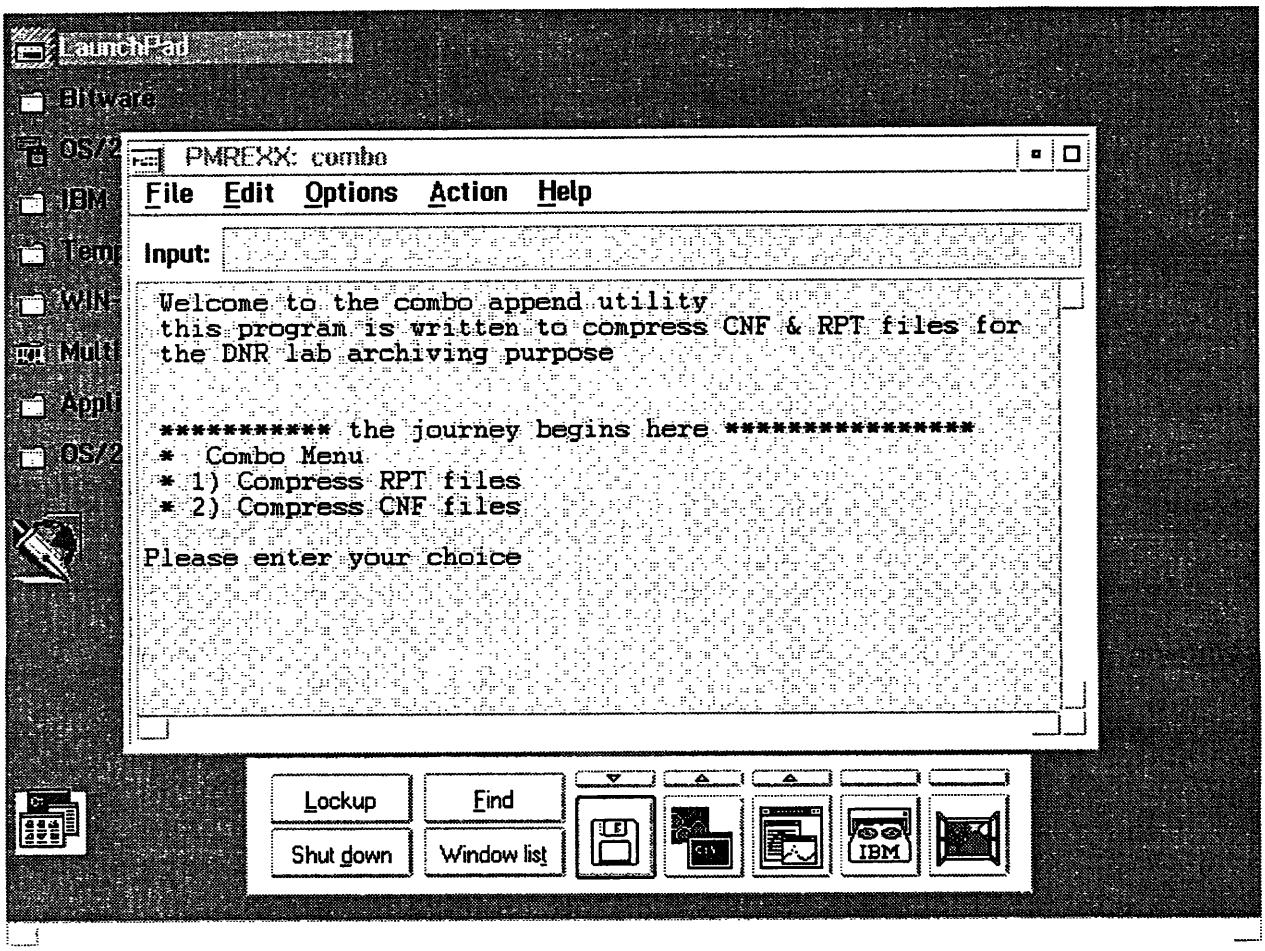


Figure 3-13. OS/2 PMREXX Window

3.16 TRANSFERRING DATA ELECTRONICALLY

Compiled radionuclide data results (Section 3.15) are delivered to Versar, Inc. electronically by using CrossTalk for Windows. To transfer data, perform the following:

1. Telephone computing services at Versar, Inc. to arrange a suitable time for data transfer. Give the path and filename to Versar staff.
2. Activate CrossTalk from Windows. Choose **fromvrsr.xwp** from the session menu. This will place the PC in **host mode**.
3. Versar staff will dial into the PC and retrieve the data file.
4. Once the session is complete, select the disconnect icon to close the connection.

3.17 BACKUP AND RESTORATION OF SYSTEM FILES

This section explains how to use the IBM DualStor backup program for backing up and restoring data from the computer's hard drive. The user may select specific files, directories, or drives to backup or restore. Backup/restoration of the system files will require data media with one of two formats, either QIC or Servo. DualStor is also capable of reading and writing the SONY QIC-WIDE QW5122F tape format. The data cartridges store up to 200MB native or 420MB compressed files. The procedure to backup data files from hard drive to tape follows:

1. Insert a preformatted tape cartridge firmly into the tape drive.
2. Select **IBM (Tape)** icon on the **Launch Pad**.
3. Choose the **Backup Basics** option from the **File** menu. A Backup Basics dialog box appears.
4. Select **Backup** from the five command buttons at the top of the dialog box.
5. Check the hard drive (**C:**) in the box below "Disk Drives."
6. Select a backup method in the box below "Method."

   Full to backup all files on the checked drives

   Incremental to backup checked files that were created or modified since the last **Full** or **Incremental** backup.
7. Check any options from the Options box.

   Erase Tape Before Backup to delete all data from the tape before backup begins.

   Use Compression to compress files being backed up to tape.

   Verify Backup to perform a byte-by-byte comparison between the data backed up on tape and the data on the hard drive. Performing a verification approximately doubles the time required for backup.
8. Select **Start** to begin the backup. The **Backing Up Files** dialog box appears providing information on the status of the backup operation. If the tape runs out of space during the backup, DualStor prompts the user to continue the backup on a second tape.
9. Select **Exit** to quit DualStor.
10. Label each tape with the date, the tape's contents, and the tape ID number.

The procedures to restore data files from tape to hard drive:

1. Insert a the backup tape cartridge firmly into the tape drive.
2. Select **IBM (Tape)** icon on the **Launch Pad**.
3. Choose the **Backup Basics** option from the **File** menu. A Backup Basics dialog box appears.
4. Select **Restore** from the five command buttons at the top of the dialog box.

5. Check each backup set to restore to the hard drive. To select individual files for restore rather than the entire backup set, select the backup set and choose **Select Files**.
6. In the **Restore To** box, select where the data should be stored.
7. In the File Overwrite box, select what DualStor should do when it attempts to overwrite a newer file on the hard drive with an older file on the backup tape.

   Do not overwrite newer files to prevent DualStor from overwriting newer files on the hard drive.

   Prompt if newer file exists to have DualStor ask the user whether or not they want to overwrite a file.

   Allow overwriting of newer files to instruct DualStor to overwrite newer files on the hard drive with older files on tape.
8. Select **Start** to begin the restore operation. The **Restore Status** dialog box appears providing information on the status of the restore operation. If the backup set is stored on two or more tapes, DualStor prompts the user when it is time to insert the next tape.

3.18 MAINTENANCE OF EQUIPMENT

Annual hardware and software support contracts for the Genie-PC system are available from Canberra, Inc. The software support contract entitles the laboratory to receive these services:

1. All Canberra software and documentation updates released.
2. Unlimited toll free telephone support.
3. Software performance reporting channels.
4. Immediate notice of critical software problems.

The hardware support offered by Canberra, Inc. includes two types of programs:

1. On site service maintenance contracts:

   This type of program offers onsite service within 24, 48 or 72 hours depending on the type of contract needed. Scheduled preventive maintenance visits, unlimited repair parts and emergency service calls are also included.

2. Extended warranty agreements

   The Extended Warranty Program is useful in applications where minimum down time is needed. A technical specialist will diagnose problems over the phone to a module or board level. Within 48 hours a new unit will be shipped.

4.0 REFERENCES

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APPENDIX A

SAMPLE RESULTS FILE

****
***** GAMMA SPECTRUM ANALYSIS *****
****

Report Generated On : 10-08-96 4:51:58 PM

Sample Title : DNR06813
Spectrum Description :
Sample Identification :
Sample Type : CLAY
Sample Geometry : 2LMAR

Peak Locate Threshold : 3.00
Peak Locate Range (in channels) : 1 - 4096
Peak Area Range (in channels) : 1 - 4096
Identification Energy Tolerance : 1.000 keV

Sample Size : 1.000E+00 UNIT

Sample Taken On : 9-12-96 12:00:00 PM
Acquisition Started : 9-23-96 4:19:36 PM

Live Time : 60000.0 seconds
Real Time : 60050.5 seconds

Energy Calibration Used Done On : 10-08-96
Efficiency Calibration Used Done On : 10-06-95

****
***** NUCLIDE IDENTIFICATION REPORT *****
****

Sample Title: DNR06813
Nuclide Library Used: C:\GENIEPC\CAMFILES\GENERAL.NLB

..... IDENTIFIED NUCLIDES .....

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (pCi/UNIT)	Activity Uncertainty
BE-7	0.947	477.60*	10.30	6.73486E+02	6.48513E+01
K-40	0.882	1460.75*	10.67	2.52489E+04	1.47179E+03
CS-137	0.976	661.66*	85.21	2.23940E+02	1.43959E+01
CE-141	0.869	145.44*	48.20	3.30376E+01	1.02378E+01
ND-147	0.434	91.11*	27.90	6.18613E+02	5.49868E+01
		319.41	1.95		
		531.02	13.10		
TL-208	0.982	72.80*	2.02	1.99901E+03	3.42927E+02
		74.97*	3.41	8.01177E+03	1.14240E+03
		277.36*	6.31	2.08982E+02	6.82131E+01
		510.77*	22.60	7.79882E+02	5.40024E+01
		583.19*	84.50	5.74094E+02	3.42983E+01
		860.56*	12.42	6.52177E+02	5.20228E+01
PB-210	1.000	46.50*	4.10	1.11133E+03	1.07941E+03
BI-212	0.760	727.18*	6.65	1.78864E+03	1.33654E+02
		785.42*	1.11	2.63938E+03	3.27677E+02
		1620.56	1.51		
PB-212	0.932	74.81*	10.50	2.60192E+03	3.75336E+02
		77.11*	17.60	2.16671E+03	2.78173E+02
		87.30*	7.90	1.68362E+03	1.63840E+02
		238.63*	43.60	1.74994E+03	1.23886E+02
		300.09	3.34		
BI-214	0.719	609.31*	44.80	1.34255E+03	8.05366E+01
		768.36*	4.80	1.44949E+03	1.18118E+02
		934.06*	3.03	1.39966E+03	1.71053E+02
		1120.29*	14.80	1.51548E+03	9.70630E+01
		1238.11*	5.86	1.65688E+03	1.32329E+02
		1377.67*	3.92	1.59996E+03	1.47597E+02
		1407.98*	2.80	1.36355E+03	2.58288E+02
		1509.23*	2.12	1.36377E+03	1.61672E+02
		1729.59	2.88		
		1764.49	15.36		
		1847.42	2.04		
PB-214	0.993	74.81*	5.90	4.63053E+03	6.88730E+02
		77.11*	9.90	3.85193E+03	5.11406E+02
		87.30*	4.41	3.01601E+03	2.87651E+02
		241.98*	7.50	1.78990E+03	1.16926E+02
		295.21*	18.50	1.41636E+03	9.16915E+01
		351.92*	35.80	1.47388E+03	8.89977E+01
RA-224	0.868	240.99*	3.97	3.38142E+03	2.18022E+02
RA-226	0.998	186.10*	3.50	3.07966E+03	2.23677E+02
AC-228	0.923	89.95*	1.94	4.29743E+03	5.15459E+02

Nuclide Name	Id Confidence	Energy (keV)	Yield (%)	Activity (pCi/UNIT)	Activity Uncertainty
AC-228	0.923	93.35*	3.20	3.84414E+03	4.85116E+02
		99.50	1.28		
		105.00*	1.47	5.29710E+02	2.40113E+02
		129.07*	2.45	1.67698E+03	2.85590E+02
		209.25*	3.88	1.31714E+03	1.46353E+02
		270.24*	3.43	1.59300E+03	1.55014E+02
		327.99*	2.95	1.26207E+03	1.63290E+02
		338.32*	11.30	1.68993E+03	1.19093E+02
		409.46*	1.94	1.26185E+03	2.13037E+02
		463.01*	4.44	1.63195E+03	1.41142E+02
		755.32*	1.01	2.07279E+03	4.13225E+02
		772.29*	1.50	1.74714E+03	1.98358E+02
		794.95*	4.34	1.57815E+03	1.35482E+02
		835.71*	1.68	1.68590E+03	2.36836E+02
		911.21*	26.60	1.73994E+03	1.10968E+02
		964.77*	5.11	1.72832E+03	1.25409E+02
		968.97*	16.20	1.78496E+03	1.15991E+02
		1588.21*	3.27	1.96419E+03	1.86422E+02
		1630.63	1.60		
TH-231	0.686	25.60	14.70		
		81.20	0.90		
		84.21*	6.60	7.70894E+02	9.89163E+01
PA-234m	0.919	1001.10*	0.80	1.60950E+03	5.22913E+02
TH-234	0.511	63.29*	4.50	1.24549E+03	4.83676E+02
		92.38	2.60		
		92.80*	2.60	4.73126E+03	1.21167E+03

* = Energy line found in the spectrum.
@ = Energy line not used for Weighted Mean Activity
Energy Tolerance : 1.000 keV
Nuclide confidence index threshold = 0.30
Errors quoted at 2.000 sigma

****
***** I N T E R F E R E N C E C O R R E C T E D R E P O R T *****
****

Nuclide Name	Nuclide Id Confidence	Wt mean Activity (pCi/UNIT)	Wt mean Activity Uncertainty
BE-7	0.947	6.734857E+02	6.485130E+01
K-40	0.882	2.524890E+04	1.471790E+03
CS-137	0.976	2.239398E+02	1.439593E+01
CE-141	0.869	3.303763E+01	1.023783E+01
ND-147	0.434	3.780732E+02	4.125771E+01
TL-208	0.982	6.106988E+02	3.131663E+01
PB-210	1.000	1.111333E+03	1.079407E+03
BI-212	0.760	1.875739E+03	1.316347E+02
PB-212	0.932	1.479614E+03	8.798875E+01
BI-214	0.719	1.439308E+03	6.980520E+01
PB-214	0.993	1.400925E+03	7.236567E+01
RA-224	0.868	7.348381E+02	1.607004E+02
RA-226	0.998	3.079661E+03	2.236767E+02
AC-228	0.923	1.671001E+03	7.407571E+01
TH-231	0.686	7.708935E+02	9.891632E+01
PA-234m	0.919	1.609496E+03	5.229133E+02
TH-234	0.511	2.331200E+03	2.419681E+02

? = nuclide is part of an undetermined solution
X = nuclide rejected by the interference analysis
@ = nuclide contains energy lines not used in Weighted Mean Activity

Errors quoted at 2.000 sigma

********** U N I D E N T I F I E D P E A K S **********

Peak Locate Performed on: 10-08-96 4:52:00 PM
Peak Locate From Channel: 1
Peak Locate To Channel: 4096

	Peak No.	Energy (keV)	Peak Size in Counts per Second	Peak CPS % Uncertainty
	1	6.44	1.3884E-01	5.76
M	2	30.58	2.5204E-02	20.41
m	3	32.61	1.2547E-01	7.41
	16	154.32	2.3190E-02	39.59
	19	216.18	6.1000E-03	132.32
M	20	236.35	9.0346E-03	29.19
	30	454.53	8.4771E-03	46.27
	34	562.73	4.9563E-03	53.04
m	38	665.91	7.8519E-03	17.59
M	41	763.54	3.1927E-03	38.40
M	44	782.32	4.6186E-03	29.75
	47	806.94	6.6375E-03	50.77
m	49	840.54	7.5359E-03	22.01
	51	904.61	4.8792E-03	42.52
	58	1155.61	1.0688E-02	25.66
	60	1247.81	1.3833E-03	121.56
	61	1281.74	4.8188E-03	40.73
M	63	1402.48	4.7392E-03	22.78
M	66	1496.63	4.0198E-03	22.66
m	67	1502.64	2.2665E-03	31.07
m	69	1513.86	1.7305E-03	38.74
M	70	1539.48	1.8320E-03	46.55
m	71	1544.22	1.9029E-03	45.75
M	72	1581.80	3.1949E-03	22.75
m	74	1593.65	6.6356E-03	15.32
	75	1621.62	5.7833E-03	18.93
	76	1631.69	7.4521E-03	16.62
	77	1662.29	2.6417E-03	41.14
	78	1730.71	1.2817E-02	10.76
	79	1765.57	5.9900E-02	4.01
	80	1848.48	7.4500E-03	17.14

M = First peak in a multiplet region
m = Other peak in a multiplet region
F = Fitted singlet

Errors quoted at 2.000 sigma

****
***** NUCLIDE MDA REPORT *****
****

Detector Name: CANB1-25
Sample Geometry: 2LMAR
Sample Title: DNR06813
Nuclide Library Used: C:\GENIEPC\CAMFILES\GENERAL.NLB

	Nuclide Name	Energy (keV)	Yield (%)	Line MDA (pCi/UNIT)	Nuclide MDA (pCi/UNIT)
+	BE-7	477.60*	10.30	1.41E+02	1.41E+02
+	K-40	1460.75*	10.67	1.34E+02	1.34E+02
	CR-51	320.08	10.08	1.24E+02	1.24E+02
	MN-54	834.83	99.98	1.31E+01	1.31E+01
	CO-57	122.06	85.90	1.19E+01	1.19E+01
		136.47	10.33	9.88E+01	
		692.41	0.16	7.26E+03	
	CO-58	511.00	29.92	5.45E+01	1.27E+01
		810.78	99.45	1.27E+01	
	FE-59	142.65	1.02	1.16E+03	3.10E+01
		192.35	3.08	4.30E+02	
		1099.25	56.50	3.10E+01	
		1291.60	43.20	3.94E+01	
	CO-60	1173.24	99.90	1.61E+01	1.36E+01
		1332.50	99.98	1.36E+01	
	ZN-65	511.00	2.83	5.32E+02	3.71E+01
		1115.55	50.70	3.71E+01	
	Y-88	511.00	0.42	3.74E+03	9.73E+00
		898.04	93.70	1.34E+01	
		1836.06	99.20	9.73E+00	
>		2734.00	0.71	0.00E+00	
	NB-95	19.60	0.02	1.15E+09	1.75E+01
		389.20	0.02	6.25E+04	
		765.80	99.90	1.75E+01	
	ZR-95	724.20	44.15	3.91E+01	2.46E+01
		756.73	54.50	2.46E+01	
	MO-99	140.51	4.52	3.97E+03	1.69E+03
		181.06	6.08	3.36E+03	
		366.43	1.15	1.51E+04	
		739.58	12.13	1.69E+03	
		778.00	4.34	4.87E+03	
	RU-103	497.08	91.00	1.34E+01	1.34E+01
		610.33	5.73	4.98E+02	
	CD-109	88.03*	3.61	3.32E+02	3.32E+02
	AG-110m	446.81	3.75	2.60E+02	1.50E+01
		620.36	2.81	3.91E+02	
		657.76	94.60	1.50E+01	
		677.62	10.35	1.11E+02	
		687.02	6.44	1.81E+02	
		706.68	16.44	7.42E+01	
		744.28	4.73	2.47E+02	
		763.94	22.29	5.88E+01	

Nuclide Name	Energy (keV)	Yield (%)	Line MDA (pCi/UNIT)	Nuclide MDA (pCi/UNIT)
AG-110m	818.03	7.34	1.54E+02	1.50E+01
	884.68	72.70	1.60E+01	
	937.49	34.36	4.04E+01	
	1384.30	24.28	6.22E+01	
	1475.79	3.99	2.40E+02	
	1505.04	13.04	9.40E+01	
	1562.30	1.03	8.99E+02	
SN-113	255.06	1.82	5.91E+02	1.66E+01
	391.69	64.00	1.66E+01	
TE-123m	159.00	84.00	1.45E+01	1.45E+01
SB-125	176.33	6.79	1.66E+02	3.38E+01
	380.43	1.52	6.37E+02	
	427.89	29.40	3.38E+01	
	463.38	10.45	1.10E+02	
	600.56	17.78	6.15E+01	
	606.64	5.02	4.65E+02	
	635.90	11.32	9.60E+01	
	671.41	1.80	6.21E+02	
I-131	80.18	2.62	1.53E+03	3.17E+01
	284.30	6.06	4.35E+02	
	364.48	81.20	3.17E+01	
	636.97	7.27	4.00E+02	
	722.89	1.80	1.91E+03	
TE-132	116.30	1.94	6.06E+03	1.44E+02
	228.16	88.20	1.44E+02	
BA-133	53.16	2.20	1.40E+03	2.41E+01
	79.62	2.62	6.52E+02	
	81.00	34.10	4.06E+01	
	160.61	0.64	1.77E+03	
	223.23	0.45	2.44E+03	
	276.40	7.16	1.47E+02	
	302.85	18.33	5.77E+01	
	356.02	62.05	2.41E+01	
	383.85	8.94	1.09E+02	
XE-133	81.00	38.00	1.67E+02	1.67E+02
XE-133m	233.22	10.00	4.24E+03	4.24E+03
CS-134	563.23	8.38	1.29E+02	1.51E+01
	569.32	15.43	6.88E+01	
	604.70	97.60	1.51E+01	
	795.84	85.40	1.61E+01	
	801.93	8.73	1.30E+02	
	1365.15	3.04	4.01E+02	
CS-136	66.88	4.79	7.52E+02	2.02E+01
	86.36	5.18	5.32E+02	
	153.25	5.75	3.76E+02	
	163.92	3.39	6.14E+02	
	176.60	10.00	2.05E+02	
	273.65	11.10	1.79E+02	
	340.55	42.20	5.99E+01	
	818.51	99.70	2.02E+01	
	1048.07	80.00	3.11E+01	

	Nuclide Name	Energy (keV)	Yield (%)	Line MDA (pCi/UNIT)	Nuclide MDA (pCi/UNIT)
	CS-136	1235.36	20.00	1.89E+02	2.02E+01
+	CS-137	661.66*	85.21	8.83E+00	8.83E+00
	BA-140	162.67	6.21	3.42E+02	7.82E+01
		304.87	4.30	4.08E+02	
		423.73	3.12	5.87E+02	
		537.31	24.39	7.82E+01	
	LA-140	328.76	20.60	5.93E+03	1.53E+03
		432.49	2.91	3.85E+04	
		487.02	44.30	2.46E+03	
		751.64	4.25	3.22E+04	
		815.77	22.90	5.51E+03	
		867.85	5.59	2.33E+04	
		919.55	2.70	5.07E+04	
		925.19	6.93	1.96E+04	
		1596.21	95.40	1.53E+03	
+	CE-141	145.44*	48.20	3.11E+01	3.11E+01
	CE-143	57.36	11.70	7.08E+04	1.09E+04
		231.55	2.05	1.76E+05	
		293.27	42.80	1.09E+04	
		350.62	3.23	1.89E+05	
		490.37	2.16	1.42E+05	
		664.57	5.69	9.55E+04	
		721.93	5.39	7.03E+04	
	CE-144	80.12	1.36	1.12E+03	9.26E+01
		133.51	11.09	9.26E+01	
+	ND-147	91.11*	27.90	8.92E+01	3.92E+01
		319.41	1.95	9.94E+02	
		531.02	13.10	1.60E+02	
+	TL-208	72.80*	2.02	7.27E+02	1.52E+01
		74.97*	3.41	4.09E+02	
		277.36*	6.31	2.08E+02	
		510.77*	22.60	7.23E+01	
		583.19*	84.50	1.52E+01	
		860.56*	12.42	9.41E+01	
+	PB-210	46.50*	4.10	1.43E+03	1.43E+03
	BI-211	351.10	12.90	1.45E+02	1.45E+02
	PB-211	404.80	2.90	3.49E+02	3.49E+02
		427.10	1.30	7.57E+02	
		832.00	2.90	4.28E+02	
+	BI-212	727.18*	6.65	1.74E+02	1.74E+02
		785.42*	1.11	7.51E+02	
		1620.56	1.51	7.36E+02	
+	PB-212	74.81*	10.50	1.33E+02	1.94E+01
		77.11*	17.60	7.51E+01	
		87.30*	7.90	1.49E+02	
		238.63*	43.60	1.94E+01	
		300.09	3.34	3.21E+02	
+	BI-214	609.31*	44.80	2.28E+01	2.28E+01
		768.36*	4.80	1.69E+02	
		934.06*	3.03	4.18E+02	
		1120.29*	14.80	1.11E+02	

	Nuclide Name	Energy (keV)	Yield (%)	Line MDA (pCi/UNIT)	Nuclide MDA (pCi/UNIT)
+	BI-214	1238.11*	5.86	3.13E+02	2.28E+01
		1377.67*	3.92	2.69E+02	
		1407.98*	2.80	2.75E+02	
		1509.23*	2.12	3.19E+02	
		1729.59	2.88	4.22E+02	
		1764.49	15.36	1.44E+02	
		1847.42	2.04	5.73E+02	
+	PB-214	74.81*	5.90	2.37E+02	3.97E+01
		77.11*	9.90	1.34E+02	
		87.30*	4.41	2.68E+02	
		241.98*	7.50	1.10E+02	
		295.21*	18.50	5.31E+01	
		351.92*	35.80	3.97E+01	
	RN-219	271.20*	10.60	1.01E+02	1.01E+02
		401.80	6.50	1.56E+02	
	RA-223	81.07	15.00	9.20E+01	5.61E+01
		83.78	24.80	5.61E+01	
		94.90	11.30	1.12E+02	
		144.20	3.26	3.05E+02	
		154.19	5.59	2.10E+02	
		269.41	13.60	8.10E+01	
		323.89	3.90	2.42E+02	
		338.32	2.78	4.95E+02	
+	RA-224	240.99*	3.97	2.08E+02	2.08E+02
+	RA-226	186.10*	3.50	3.17E+02	3.17E+02
	TH-227	50.20	8.50	4.30E+02	1.48E+02
		79.77	2.10	8.10E+02	
		88.47	2.66	5.61E+02	
		236.00	11.20	1.59E+02	
		256.25	6.80	1.48E+02	
		299.90	2.00	5.36E+02	
		329.82	2.80	3.76E+02	
+	AC-228	89.95*	1.94	6.20E+02	5.59E+01
		93.35*	3.20	3.61E+02	
		99.50	1.28	8.59E+02	
		105.00*	1.47	7.37E+02	
		129.07*	2.45	6.65E+02	
		209.25*	3.88	3.26E+02	
		270.24*	3.43	3.11E+02	
		327.99*	2.95	3.50E+02	
		338.32*	11.30	1.06E+02	
		409.46*	1.94	5.75E+02	
		463.01*	4.44	2.53E+02	
		755.32*	1.01	1.10E+03	
		772.29*	1.50	5.39E+02	
		794.95*	4.34	2.29E+02	
		835.71*	1.68	4.77E+02	
		911.21*	26.60	5.59E+01	
		964.77*	5.11	1.72E+02	
		968.97*	16.20	5.60E+01	
		1588.21*	3.27	2.09E+02	

	Nuclide Name	Energy (keV)	Yield (%)	Line MDA (pCi/UNIT)	Nuclide MDA (pCi/UNIT)
+	AC-228	1630.63	1.60	7.10E+02	5.59E+01
	TH-228	84.37*	1.27	9.78E+02	9.78E+02
		215.99*	0.26	5.03E+03	
	PA-231	283.67	1.60	6.08E+02	4.47E+02
		300.02	2.40	4.47E+02	
		302.65	1.60	6.59E+02	
		330.06	1.30	8.13E+02	
+	TH-231	25.60	14.70	2.93E+04	1.88E+02
		81.20	0.90	1.53E+03	
		84.21*	6.60	1.88E+02	
+	PA-234m	1001.10*	0.80	1.59E+03	1.59E+03
+	TH-234	63.29*	4.50	6.16E+02	4.44E+02
		92.38	2.60	5.35E+02	
		92.80*	2.60	4.44E+02	
	U-234	53.20	0.12	2.60E+04	2.60E+04
	U-235	89.95*	2.80	4.29E+02	1.08E+02
		93.35*	4.50	2.57E+02	
		105.00*	2.10	5.16E+02	
		143.76*	10.90	1.08E+02	
		163.33	5.00	2.27E+02	
		205.31	5.00	2.21E+02	
	NP-239	99.55	13.90	2.35E+03	1.38E+03
		103.76	22.30	1.41E+03	
		106.12	22.90	1.38E+03	
		117.00	10.50	2.86E+03	
		209.75	3.27	1.08E+04	
		228.18	10.80	3.02E+03	
		277.60	14.20	2.20E+03	
		334.31	2.04	1.50E+04	
	AM-241	59.54	35.90	6.67E+01	6.67E+01

+ = Nuclide identified during the nuclide identification
* = Energy line found in the spectrum
> = MDA value not calculated
@ = Half-life too short to be able to perform the decay correction

APPENDIX B

SAMPLE RADIONUCLIDE LIBRARY

****
***** L I B R A R Y L I S T I N G R E P O R T *****
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Nuclide Library Title:

Nuclide Library Description: general nuclide library

Nuclide Name	Half-Life (Seconds)	Energy (keV)	Energy Uncert. (keV)	Yield (%)	Yield Uncert.(Abs.+-)
BE-7	4.605E+06	477.600*	0.100	10.3000	0.1000
K-40	4.030E+16	1460.750*	0.060	10.6700	0.1100
CR-51	2.394E+06	320.084*	0.001	10.0800	0.2300
MN-54	2.697E+07	834.827*	0.021	99.9760	0.0010
CO-57	2.348E+07	122.061*	0.000	85.9000	1.2000
		136.474	0.001	10.3300	0.1000
		692.410	0.070	0.1620	0.0050
CO-58	6.127E+06	511.000	0.000	29.9200	0.0000
		810.775*	0.009	99.4480	0.0080
FE-59	3.844E+06	142.652	0.002	1.0200	0.0400
		192.349	0.005	3.0800	0.1000
		1099.251*	0.004	56.5000	1.5000
		1291.596	0.007	43.2000	1.1000
CO-60	1.663E+08	1173.237	0.004	99.9000	0.0200
		1332.501*	0.005	99.9820	0.0010
ZN-65	2.107E+07	511.000	0.000	2.8300	0.0000
		1115.546*	0.004	50.7000	0.1300
Y-88	9.215E+06	511.000	0.000	0.4200	0.0000
		898.042	0.003	93.7000	0.3000
		1836.063*	0.012	99.2000	0.3000
		2734.000	0.500	0.7100	0.0700
NB-95	3.033E+06	19.600	0.100	0.0200	0.1000
		389.200	0.100	0.0200	0.1000
		765.800*	0.100	99.9000	0.1000
ZR-95	5.531E+06	724.199	0.005	44.1500	0.2300
		756.729*	0.012	54.5000	0.2000
MO-99	2.374E+05	140.511	0.001	4.5200	0.2400
		181.063	0.008	6.0800	0.1300
		366.430	0.030	1.1500	0.0400
		739.580*	0.060	12.1300	0.1800
		778.000	0.200	4.3400	0.1300
RU-103	3.392E+06	497.084*	0.006	91.0000	3.0000
		610.330	0.020	5.7300	0.1900
RU-106	3.219E+07	616.181	0.000	0.7380	0.0000
		621.920*	0.000	9.8000	0.0000
		873.470	0.000	0.4300	0.0000
		1050.360	0.000	1.5300	0.0000
		1128.042	0.000	0.3980	0.0000
		1562.220	0.000	0.1580	0.0000
CD-109	3.999E+07	88.034*	0.001	3.6100	0.1000
AG-110m	2.158E+07	446.811	0.003	3.7500	0.0300
		620.360	0.003	2.8060	0.0180
		657.762*	0.002	94.6000	0.4000
		677.623	0.002	10.3500	0.0800

Library Title:

Nuclide Name	Half-Life (Seconds)	Energy (keV)	Energy Uncert. (keV)	Yield (%)	Yield Uncert.(Abs.+-)
AG-110m	2.158E+07	706.682	0.003	16.4400	0.1000
		744.277	0.003	4.7300	0.0300
		763.944	0.003	22.2900	0.0900
		818.031	0.004	7.3400	0.0400
		884.685	0.003	72.7000	0.3000
		937.493	0.004	34.3600	0.1200
		1384.300	0.004	24.2800	0.0800
		1475.788	0.006	3.9950	0.0170
		1505.040	0.005	13.0400	0.0500
		1562.302	0.005	1.0290	0.0070
SN-113	9.944E+06	255.060	0.050	1.8200	0.0900
		391.688*	0.015	64.0000	2.0000
TE-123m	1.034E+07	159.000*	0.030	84.0000	0.4000
SB-125	8.615E+07	176.334	0.011	6.7900	0.0700
		380.435	0.020	1.5200	0.0190
		427.889*	0.015	29.4000	0.3000
		463.383	0.015	10.4500	0.1100
		600.557	0.018	17.7800	0.1800
		606.641	0.019	5.0200	0.0600
		635.895	0.018	11.3200	0.1200
		671.409	0.020	1.8000	0.0500
I-131	6.947E+05	80.183	0.010	2.6200	0.0500
		284.298	0.011	6.0600	0.0900
		364.480*	0.011	81.2000	1.2000
		636.973	0.010	7.2700	0.1100
		722.893	0.010	1.8000	0.0300
TE-132	2.815E+05	116.300	0.080	1.9400	0.1800
		228.160*	0.060	88.2000	0.4000
BA-133	3.320E+08	53.161	0.001	2.1990	0.0220
		79.623	0.010	2.6200	0.0600
		80.997	0.003	34.1000	0.3000
		160.613	0.008	0.6450	0.0080
		223.234	0.012	0.4500	0.0040
		276.398	0.002	7.1640	0.0220
		302.853	0.001	18.3300	0.0600
		356.017*	0.002	62.0500	0.1900
		383.851	0.003	8.9400	0.0300
XE-133	4.530E+05	80.997*	0.003	38.0000	0.7000
XE-133m	1.892E+05	233.221*	0.018	10.0000	0.0000
CS-134	6.507E+07	563.227	0.015	8.3800	0.0500
		569.315	0.015	15.4300	0.1100
		604.699*	0.015	97.6000	0.4000
		795.845	0.022	85.4000	0.4000
		801.932	0.022	8.7300	0.0400
		1365.150	0.040	3.0400	0.0400
CS-136	1.137E+06	66.881	0.017	4.7900	0.2000
		86.360	0.030	5.1800	0.2000
		153.246	0.004	5.7500	0.1800
		163.920	0.002	3.3900	0.1200
		176.602	0.004	10.0000	0.4000
		273.646	0.008	11.1000	0.4000

Library Title:

Nuclide Name	Half-Life (Seconds)	Energy (keV)	Energy Uncert. (keV)	Yield (%)	Yield Uncert.(Abs.+-)
CS-136	1.137E+06	818.514*	0.012	99.7000	0.0000
		1048.073	0.020	80.0000	3.0000
		1235.362	0.023	20.0000	0.7000
CS-137	9.467E+08	661.660*	0.003	85.2100	0.0700
BA-140	1.102E+06	162.672	0.002	6.2100	0.0800
		304.874	0.007	4.3000	0.0600
		423.732	0.004	3.1200	0.0800
		537.311*	0.003	24.3900	0.2200
LA-140	1.450E+05	328.762	0.008	20.6000	0.4000
		432.493	0.012	2.9100	0.0300
		487.021	0.012	44.3000	0.8000
		751.637	0.018	4.2500	0.0500
		815.772	0.019	22.9000	0.4000
		867.846	0.020	5.5900	0.0500
		919.550	0.023	2.7000	0.0400
		925.189	0.021	6.9300	0.0800
		1596.210*	0.040	95.4000	0.0800
CE-141	2.808E+06	145.440*	0.003	48.2000	0.3000
CE-143	1.192E+05	57.356	0.007	11.7000	0.4000
		231.550	0.002	2.0500	0.0500
		293.266*	0.002	42.8000	0.5000
		350.619	0.003	3.2300	0.0400
		490.368	0.005	2.1600	0.0300
		664.571	0.015	5.6900	0.0700
		721.929	0.013	5.3900	0.0700
CE-144	2.462E+07	80.120	0.005	1.3600	0.0600
		133.515*	0.002	11.0900	0.2000
ND-147	9.487E+05	91.106*	0.020	27.9000	1.1000
		319.411	0.018	1.9500	0.1400
		531.016	0.022	13.1000	0.9000
TL-208	3.156E+11	72.804	0.001	2.0200	0.0700
		74.969	0.001	3.4100	0.1100
		277.358	0.010	6.3100	0.0900
		510.770	0.100	22.6000	0.3000
		583.191*	0.002	84.5000	0.7000
		860.564	0.005	12.4200	0.1000
PB-210	3.156E+11	46.500*	0.100	4.1000	1.0000
BI-211	3.156E+11	351.100*	0.100	12.9000	0.1000
PB-211	3.156E+11	404.800	0.100	2.9000	0.1000
		427.100	0.100	1.3000	0.1000
		832.000*	0.100	2.9000	0.1000
BI-212	3.156E+11	727.180*	0.060	6.6500	0.1500
		785.420	0.060	1.1100	0.0300
		1620.560	0.070	1.5100	0.0500
PB-212	3.156E+11	74.810	0.000	10.5000	0.4000
		77.110	0.000	17.6000	0.7000
		87.300	0.000	7.9000	0.4000
		238.633*	0.004	43.6000	1.3000
		300.087	0.010	3.3400	0.1100
BI-214	3.156E+11	609.312*	0.007	44.8000	0.5000
		768.356	0.010	4.8000	0.0700

Library Title:

Nuclide Name	Half-Life (Seconds)	Energy (keV)	Energy Uncert. (keV)	Yield (%)	Yield Uncert.(Abs.+-)
BI-214	3.156E+11	1120.287	0.010	14.8000	0.2000
		1238.110	0.012	5.8600	0.0800
		1377.669	0.012	3.9200	0.0800
		1407.980	0.040	2.8000	0.4000
		1509.228	0.015	2.1200	0.0400
		1729.595	0.015	2.8800	0.0600
		1764.494	0.014	15.3600	0.2000
		1847.420	0.030	2.0400	0.0400
PB-214	3.156E+11	74.810	0.000	5.9000	0.3000
		77.110	0.000	9.9000	0.5000
		87.300	0.000	4.4100	0.2100
		241.981	0.008	7.5000	0.1000
		295.213	0.008	18.5000	0.3000
		351.921*	0.008	35.8000	0.5000
RN-219	3.156E+11	271.200*	0.100	10.6000	0.1000
		401.800	0.100	6.5000	0.1000
RA-223	3.156E+11	81.070	0.020	15.0000	0.4000
		83.780*	0.020	24.8000	0.7000
		94.900	0.000	11.3000	0.4000
		144.200	0.040	3.2600	0.0700
		154.190	0.030	5.5900	0.1000
		269.410	0.030	13.6000	0.3000
		323.890	0.040	3.9000	0.0900
		338.320	0.060	2.7800	0.0700
RA-224	3.156E+11	240.987*	0.006	3.9700	0.0400
RA-226	3.156E+11	186.100*	0.100	3.5000	0.0500
TH-227	3.156E+11	50.200	0.100	8.5000	1.8000
		79.770	0.060	2.1000	0.5000
		88.470	0.010	2.6600	0.1700
		236.000*	0.080	11.2000	2.4000
		256.250	0.050	6.8000	1.5000
		299.900	0.100	2.0000	0.5000
		329.820	0.100	2.8000	0.6000
AC-228	3.156E+11	89.953	0.002	1.9400	0.1600
		93.350	0.002	3.2000	0.3000
		99.497	0.006	1.2800	0.0800
		105.000	0.000	1.4700	0.1200
		129.065	0.003	2.4500	0.1900
		209.253	0.006	3.8800	0.1100
		270.243	0.004	3.4300	0.0800
		327.995	0.002	2.9500	0.1600
		338.322	0.002	11.3000	0.3000
		409.456	0.005	1.9400	0.0600
		463.005	0.004	4.4400	0.1100
		755.315	0.004	1.0100	0.0600
		772.291	0.004	1.5000	0.0700
		794.947	0.006	4.3400	0.1100
		835.710	0.006	1.6800	0.1100
		911.205*	0.004	26.6000	0.7000
		964.770	0.010	5.1100	0.1400
		968.971	0.010	16.2000	0.4000

Library Title:

Nuclide Name	Half-Life (Seconds)	Energy (keV)	Energy Uncert. (keV)	Yield (%)	Yield Uncert.(Abs.+-)
AC-228	3.156E+11	1630.627	0.010	1.6000	0.0800
TH-228	3.156E+11	84.373*	0.003	1.2660	0.0240
		215.985	0.005	0.2630	0.0040
PA-231	3.156E+11	283.670	0.060	1.6000	0.4000
		300.020*	0.050	2.4000	0.5000
		302.650	0.050	1.6000	0.4000
		330.060	0.050	1.3000	0.3000
TH-231	3.156E+11	25.600*	0.100	14.7000	1.0000
		81.200	0.000	0.9000	0.0000
		84.214	0.003	6.6000	0.5000
PA-234m	3.156E+11	1001.100*	0.000	0.8000	0.0000
TH-234	3.156E+11	63.290*	0.020	4.5000	0.9000
		92.380	0.010	2.6000	0.6000
		92.800	0.020	2.6000	0.6000
U-234	3.156E+11	53.200*	0.050	0.1180	0.0100
U-235	3.156E+11	89.953	0.002	2.8000	0.9000
		93.350	0.002	4.5000	1.4000
		105.000	0.000	2.1000	0.7000
		143.760*	0.020	10.9000	0.2300
		163.330	0.020	5.0000	0.1200
		205.311	0.010	5.0000	0.2100
NP-239	2.035E+05	99.550	0.050	13.9000	0.8000
		103.760	0.050	22.3000	1.2000
		106.123*	0.002	22.9000	1.2000
		117.000	0.000	10.5000	0.6000
		209.753	0.002	3.2700	0.2400
		228.183	0.001	10.8000	0.6000
		277.599	0.001	14.2000	0.2000
		334.310	0.002	2.0400	0.1800
AM-241	1.364E+10	59.537*	0.001	35.9000	0.4000

* = key line

TOTALS: 57 Nuclides 231 Energy Lines

APPENDIX C

RADIONUCLIDE SUPPLIERS

RADIONUCLIDE SUPPLIERS

Address	Telephone
Amersham Corporation 2636 South Clearbrook Drive Arlington Heights, Illinois 60005	312 593-6300 800 323-6695
Analytics, Inc. 1380 Seaboard Industrial Boulevard Atlanta, Georgia 30318	404 352-8677
Du Pont NEN Research Products 549 Albany Street Boston, Massachusetts 02118	800 551-2121
National Institute of Standards and Technology Radioactivity Group Building 245/C114 Gaithersburg, Maryland 20899	301 975-5531
North American Scientific, Inc. 7435 Greenbush Avenue North Hollywood, California 91605-9823	818 503-9201
U.S. Department of Energy c/o Martin Marietta Energy Systems, Inc. Oak Ridge National Laboratory Isotope Distribution Office P.O. Box 2009 Oak Ridge, Tennessee 37831-8044	615 574-6984

APPENDIX D

TECHNICAL SUPPORT

TECHNICAL SUPPORT

IBM Corporation
PC Help Center
P.O. Box 12195
Research Triangle Park, NC 27709

800 772-2227

Canberra Industries, Inc.
Customer Services
800 Research Parkway
Meriden, CT 06450
(System #: 96-7176)

800 255-6370